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FINAL REPORT

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Plowshare civil, industrial and scientific uses for nuclear explosives

UNITED STATES ATOMIC ENERGY COMMISSION / PLOWSHARE PROGRAM

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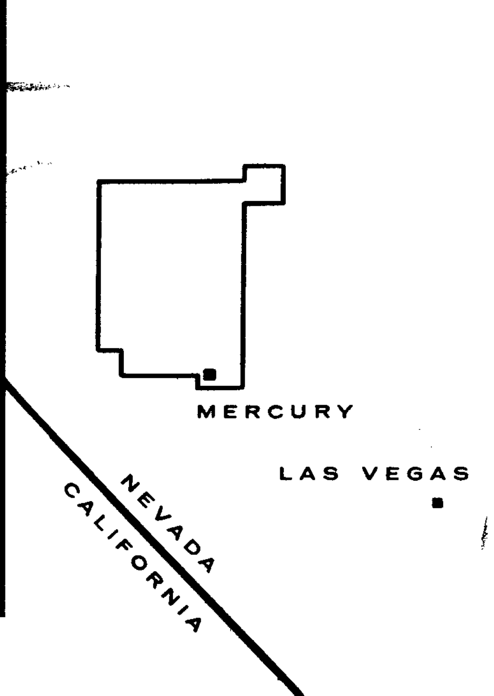

project DUGOUT

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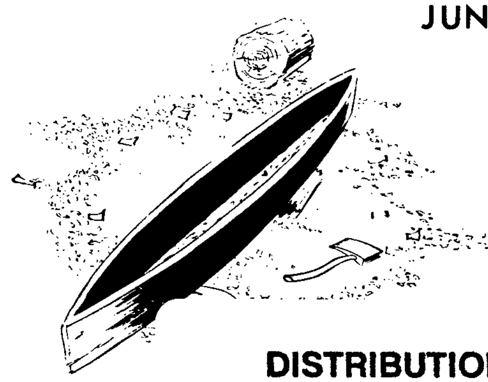

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GEOLOGIC AND ENGINEERING PROPERTIES INVESTIGATIONS

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Livermore, California

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PROJECT DUGOUT

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GEOLOGIC AND ENGINEERING PROPERTIES INVESTIGATIONS

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Experiment Station
Corps of Engineers
Vicksburg, Mississippi

December 1967

ABSTRACT

The Dugout event was a row cratering experiment in which five 20-ton nitromethane charges spaced 45 feet apart at depths of 59 feet in dry basalt were detonated simultaneously. The explosion produced an apparent crater about 135 feet wide, 285 feet long, and 35 feet deep. Preshot and postshot NX core and calyx hole drilling, trenching, laboratory analysis of core samples, and analysis of photographs have revealed preshot structure, the extent and characteristics of the ejecta and fallback, the zone of blast fracturing, the zone of bulking, and a sheared zone.

As revealed by preshot drilling, the upper basalt layer consists of about 40 feet of vesicular basalt overlying, with a gradational contact, about 50 feet of dense basalt. The vesicular basalt has been subdivided into four types on the basis of vesicle content and fabric. From 2 to 14 feet of silt overlies the bedrock.

Unconfined compressive strength for 6 samples ranges from about 7,000 to 17,000 psi. Samples of dense basalt tested triaxially show a greater increase of strength with confining pressure than does a sample of vesicular basalt. Dynamic laboratory tests gave a compression wave velocity of 16,000 ft/sec for dense basalt and about 13,000 ft/sec for slightly vesicular basalt, and they indicated that Poisson's ratio averages about 0.25. Field seismic and vibratory studies indicate compression and shear wave velocities of about 1,000 and

700 ft/sec, respectively, in the surface soil and 4,000 and 1,300 ft/sec, respectively, in highly vesicular basalt.

Flow layers complicating the otherwise simple stratigraphy form a system of nested cylinders with a mutual axis that parallels the direction of flow of the lava while it was still partly molten. Natural and blast-induced fractures have a preferred orientation parallel to flow layers. A second preferred orientation of joints is perpendicular to flow layers, but one major set of this group oriented normal to the cylinder axis is believed to be the dominant structural element modifying the crater process.

A more or less continuous blanket of ejecta extends as far as 500 feet (in one direction) laterally from the preshot position of the line of charges. This granular material has a bulking factor of about 1.39. In the subsurface, the zone of in situ bulking and the zone of blast fracturing extend laterally as far as 250 feet, but in detail there appears to be a concentration of fracturing at a depth of about 60 feet. A zone of shear deformation extends at least as far laterally from the row charge as 100 feet. In each of these three subsurface zones the intensity of deformation decreases outward.

The zone of blast fracturing along the projection of the row charge extends only about 160 feet from the end charge position, and the zone of shear deformation extends about 140 feet. A fourth zone

characterized by relative displacement of points toward the crater with respect to points below is evident along the lip at the west end of the crater.

PREFACE

The geological engineering studies described in this report were conducted by the U. S. Army Engineer Waterways Experiment Station (WES), the U. S. Army Engineer Nuclear Cratering Group (NCG), and several private contractors. Although the responsibility for the final report was assigned to WES by NCG, each organization made sizeable contributions. These contributions are mentioned under Field Investigations (Section 1.5), or at the beginning of the pertinent section.

The drilling program was under the direction of Mr. T. B. Goode, Embankment and Foundation Branch, Soils Division. Logging of borings, mapping of calyx holes and trench walls, and collecting of field data were accomplished by Mr. R. W. Hunt and Dr. R. J. Lutton, Geology Branch, Soils Division. Physical tests of cores were performed by Mr. K. L. Saucier, Engineering Materials Branch, Concrete Division.

LT R. C. Nugent contributed to the early stages of report preparation. The report was written by Dr. Lutton with the help of Mr. D. M. Bailey, Mr. Hunt, and SP 4 L. D. Carter, under the supervision of Dr. C. R. Kolb and Mr. W. B. Steinriede, Jr., Geology Branch, and Messrs. J. R. Compton and W. C. Sherman, Jr., Embankment and Foundation Branch, all under the supervision of Messrs W. J. Turnbull and A. A. Maxwell, Soils Division. NCG personnel associated

with the project were Messrs. P. R. Fisher, A. D. Frandsen, and A. L. Remboldt.

Directors of the NCG during the conduct of this study and the preparation of the report were LTC E. C. Graves, Jr., and LTC W. J. Slazak. Directors of the WES were COL A. G. Sutton, Jr., and COL J. R. Oswalt, Jr. Technical Director of the WES was Mr. J. B. Tiffany.

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CHAPTER 1

INTRODUCTION

Project Dugout was a chemical explosive row-charge cratering experiment in the hard, dry basalt of Buckboard Mesa, Nevada Test Site (NTS) (Figure 1.1) conducted as part of the Plowshare Program for development of nuclear excavation technology (Reference 1). It consisted of five 20-ton charges of nitromethane spaced linearly at 45-foot intervals at a depth of 59 feet and detonated simultaneously.

1.1 PURPOSE OF PROJECT

The purpose of the project was to extend knowledge of row-charge phenomenology from alluvial and playa media to hard, dry basalt rock.

1.2 SCOPE OF THIS REPORT

This report, one of several on Project Dugout, is limited to describing conditions and material properties bearing on the engineering aspects of crater excavation. It presents the results of the preshot and postshot geological engineering investigations by the U. S. Army Engineer Waterways Experiment Station (WES) and the U. S. Army Engineer Nuclear Cratering Group (NCG).

Major aspects investigated are as follows: (1) the crater configuration, (2) deformation of the basalt outside the true crater, (3) the relation of the crater configuration and bulk deformation to

the natural joint system and in turn to the natural primary structure of the basalt, (4) the grain size of the ejecta blanket, (5) the extent of the blast-fractured zone, and (6) the extent of the bulked zone.

1.3 PREVIOUS WORK

The earliest geological investigations on Buckboard Mesa in connection with cratering experiments were conducted as part of Project Buckboard (Reference 2), a series of 13 high-explosive events detonated in the summer of 1960. In this work, data from cores and from the emplacement holes were evaluated to determine the effect of geologic factors on crater shapes and sizes and on the distribution of ejecta (Reference 3).

In 1961, resistivity measurements were made, and core holes were drilled in the immediate vicinity of the Project Danny Boy site (References 4 through 7). Results of postshot geological investigations conducted there by the Lawrence Radiation Laboratory (LRL) and a final report of investigations by WES have been published (References 8, 9, and 10).

Subsequently, extensive geological engineering field investigations have been carried out for cratering experiments conducted on Buckboard Mesa by NCG during Projects Pre-Schooner and Sulky, and final reports have been prepared (References 11 and 12).

1.4 LOCATION

The Dugout site is on the southern half of Buckboard Mesa (Figure 1.2). The geographic locations of the core holes are given in Tables 1.1 and 1.2 in coordinates of the Nevada state coordinate system.

1.5 FIELD AND LABORATORY INVESTIGATIONS

Four areas were investigated for possible use as the Dugout site after examination of subsurface data collected on Buckboard Mesa during previous investigations (Reference 13) revealed several promising areas.

Borings NCG 20 through NCG 24, drilled in December 1963 and February 1964 exploring an area centered at N 852,600 E 594,200,[1] encountered relatively heterogeneous basalt with a relatively poor core recovery. A vibratory seismic investigation was also conducted at this location, and it revealed a thick layer of soil over part of the area.

The area centered at N 854,315 E 591,750 is penetrated by borings NCG 1.1, 1.2, and 1.3 of the previous investigations. Additional borings, NCG 27, 31, 32, 33, and 34, were drilled in March 1964 for the Dugout site selection investigations. A third site

[1] Nevada state coordinates.

west of this area was investigated, but it also did not exhibit the required subsurface conditions.

The area finally selected for the Dugout experiment was explored by a total of 15 NX holes including those used for site selection (Figure 1.3). Most of these holes were photographed by borehole camera, and all cores were logged. The walls of the 10 calyx holes drilled to about a 64-foot depth by Cannon Drilling Co. in February and March 1964 were mapped in detail.

Representative core samples from the selected site were tested in the laboratory to determine the physical properties of the basalt. Studies conducted for design and installation of the lining and stemming of the charge are reported elsewhere (Reference 14).

After emplacement of charges on the day before detonation, the site was photographed from the air by American Aerial Surveys, Inc., and subsequently a topographic map was prepared. Postshot topographic maps were also prepared from aerial photographs taken on the day after detonation. Subsequently, the lip and true crater were explored by trenching along lines extending west and south from the crater. A portion of the south trench provided a sample for bulk density determination. The structure exposed in one wall of each trench was mapped in detail. Four of the calyx holes not used for charge emplacement were remapped to determine effects of the blast.

Closeup photographs of the surface rubble were obtained along

radials from the crater for rubble grain size analysis.

The final portion of the field investigations that had continued intermittently over a period of more than two years consisted of drilling five NX core holes along the south trench during June 1965. All cores were logged, and each hole was photographed with the borehole camera.

TABLE 1.1 SUMMARY OF RESULTS OF SITE SELECTION AND PRESHOT INVESTIGATIONS FOR PROJECT DUGOUT

NCG Core Boring Number	Coordinates[a]		Ground Elevation	Total Depth	Core Recovery	Type of Boring	Angle of Boring	Borehole Camera Log
			feet msl	feet	percent		degrees	interval, feet
1.1	N 854,571.39	E 591,611.18	5419.0	126.7	97	NX	Vertical	None
1.2	N 854,558.83	E 591,437.33	5416.7	120.0	99	NX	Vertical	None
1.3	N 854,581.08	E 591,787.53	5414.0	30.6	21	NX	Vertical	None
2.1	N 853,092.20	E 593,391.96	5393.3	100.0	89	NX	Vertical	1.0 to 74.8
20	N 852,759.04	E 594,574.89	5385.2	200.2	71	NX	Vertical	None
21	N 852,622.86	E 594,044.36	5382.5	29.3	50	NX	Vertical	None
22	N 852,511.41	E 594,089.59	5383.0	41.1	59	NX	Vertical	None
23	N 852,795.41	E 594,122.02	5384.7	121.4	91	NX	Vertical	None
24	N 852,816.89	E 594,297.57	5384.9	14.8	75	NX	Vertical	None
25	N 853,287.49	E 593,975.52	5386.8	120.3	97	NX	Vertical	None
26	N 853,289.83	E 594,149.94	5383.7	121.7	93	NX	Vertical	2.0 to 119.3
27	N 854,323.94	E 591,876.57	5419.1	120.0	100	NX	Vertical	1.0 to 118.2
28	N 855,161.38	E 590,252.48	5381.9	31.5	90	NX	Vertical	None
29	N 854,683.70	E 590,346.23	5380.4	81.2	92	NX	Vertical	None
30	N 853,285.24	E 593,799.62	5388.5	120.8	93	NX	Vertical	1.0 to 112.7
31	N 854,310.88	E 591,646.40	5418.7	120.2	98	NX	Vertical	1.0 to 119.5
32	N 854,316.15	E 591,762.58	5419.9	66.3	83	NX	Vertical	None
33	N 854,570.48	E 591,666.71	5418.1	96.0	94	NX	Vertical	None
34	N 854,315.30	E 591,752.60	5419.2	257.9	98	NX	Vertical	1.0 to 248.5
35	N 853,289.80	E 593,909.90	5387.5	80.0	97	NX	Vertical	1.0 to 70.0
36	N 853,289.83	E 594,029.99	5386.1	200.0	72	NX	Vertical	7.4 to 100.0
37	N 853,259.80	E 593,984.90	5387.0	80.0	100	NX	Vertical	3.0 to 78.0
38	N 853,259.80	E 594,052.40	5386.0	81.4	96	NX	Vertical	5.5 to 80.5
39	N 853,229.80	E 594,052.40	5386.0	81.5	100	NX	Vertical	5.0 to 80.0
40	N 853,319.80	E 594,007.40	5386.3	80.0	94	NX	Vertical	3.0 to 78.0
41	N 853,319.80	E 594,074.90	5385.0	81.0	98	NX	Vertical	5.0 to 79.5
42	N 853,349.81	E 594,074.97	5384.7	80.0	99	NX	Vertical	None
42A	N 853,349.81	E 594,079.97	5384.7	81.0	96	NX	Vertical	5.0 to 80.0
43	N 853,289.90	E 593,684.90	5389.5	120.0	97	NX	Vertical	3.0 to 114.0
44	N 853,230.02	E 593,985.00	5386.9	121.0	99	NX	60 North	12.0 to 102.7
45	N 853,230.02	E 593,980.00	5386.9	120.3	99	NX	60 West	10.0 to 116.7

[a] Nevada state coordinate system.

TABLE 1.2 DESCRIPTION OF CALYX BORINGS

Boring	Location[a]		Ground Elevation[b]	Total Depth	Angle of Boring	Type of Boring
			feet msl	feet		
U18G	N 853,289.90	E 594,120.20	5384.44	65.2	Vertical	36-inch calyx
U18H	N 853,290.00	E 594,075.00	5385.29	65.2	Vertical	36-inch calyx
U18I	N 853,289.94	E 594,030.06	5386.31	64.0	Vertical	36-inch calyx
U18J	N 853,290.00	E 593,985.12	5386.72	64.0	Vertical	36-inch calyx
U18K	N 853,290.10	E 593,940.00	5387.36	64.2	Vertical	36-inch calyx
U18L	N 853,290.00	E 593,895.02	5387.82	64.0	Vertical	36-inch calyx
U18M	N 853,290.00	E 593,850.04	5388.05	64.0	Vertical	36-inch calyx
U18N	N 853,290.00	E 593,805.06	5388.56	64.0	Vertical	36-inch calyx
U18O	N 853,290.00	E 593,760.08	5388.75	64.0	Vertical	36-inch calyx
U18P	N 853,290.00	E 593,715.10	5389.58	64.0	Vertical	36-inch calyx

[a] Nevada state coordinate system.
[b] Elevations shown on individual logs in Appendix B are tops of drilling pads.

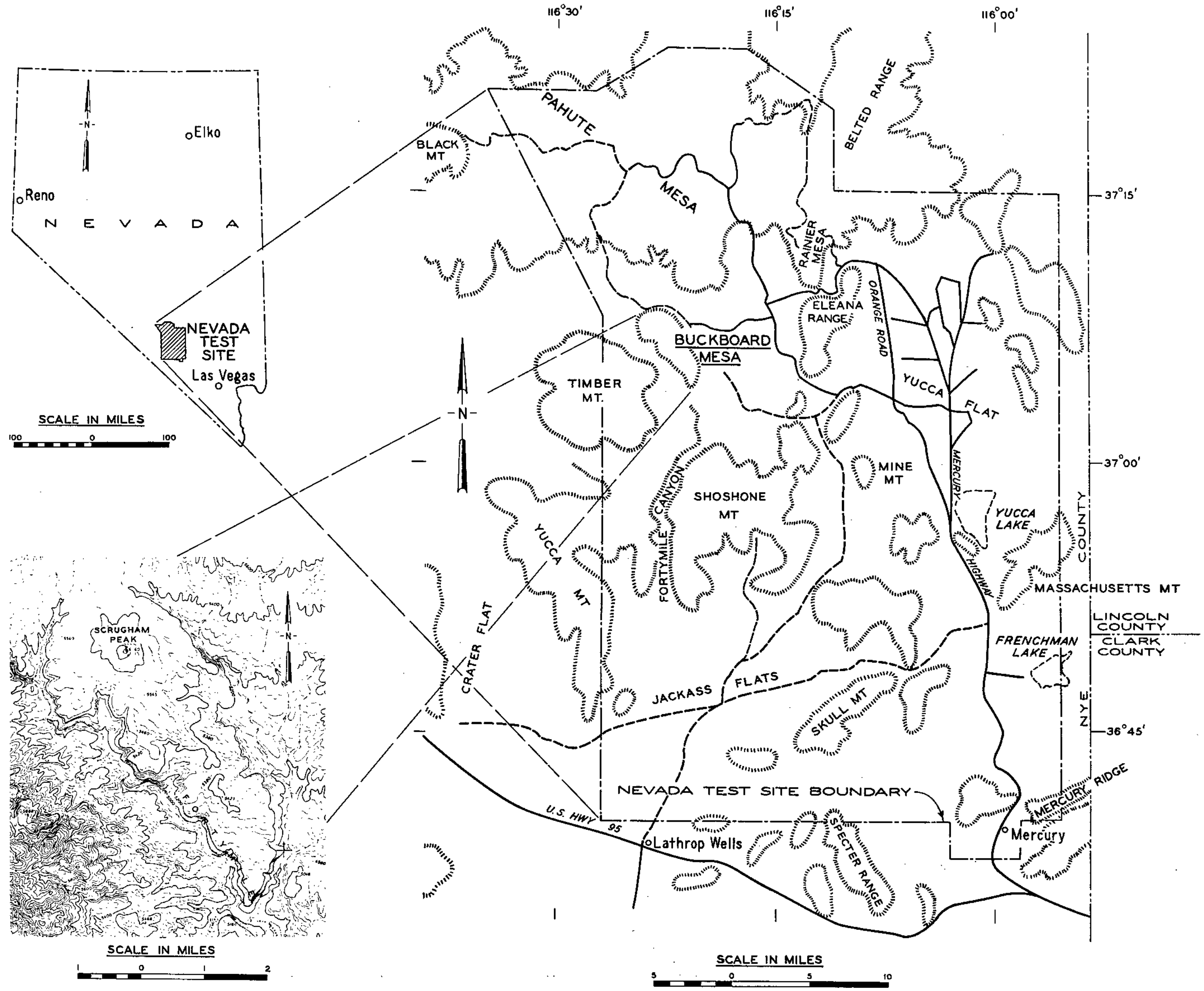


Figure 1.1 Location of Buckboard Mesa and Nevada Test Site.

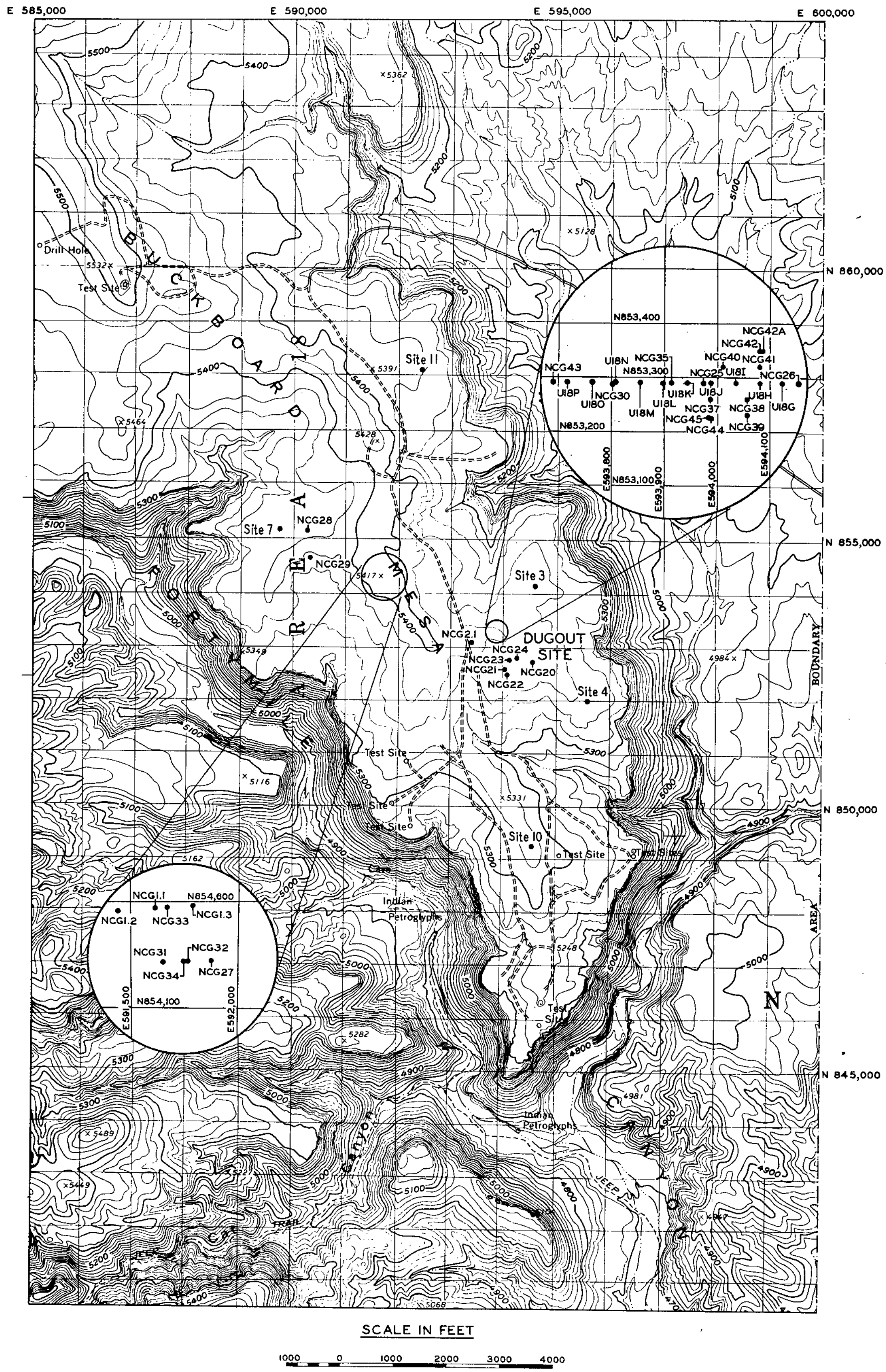


Figure 1.2 Location of Dugout and other sites on Buckboard Mesa.

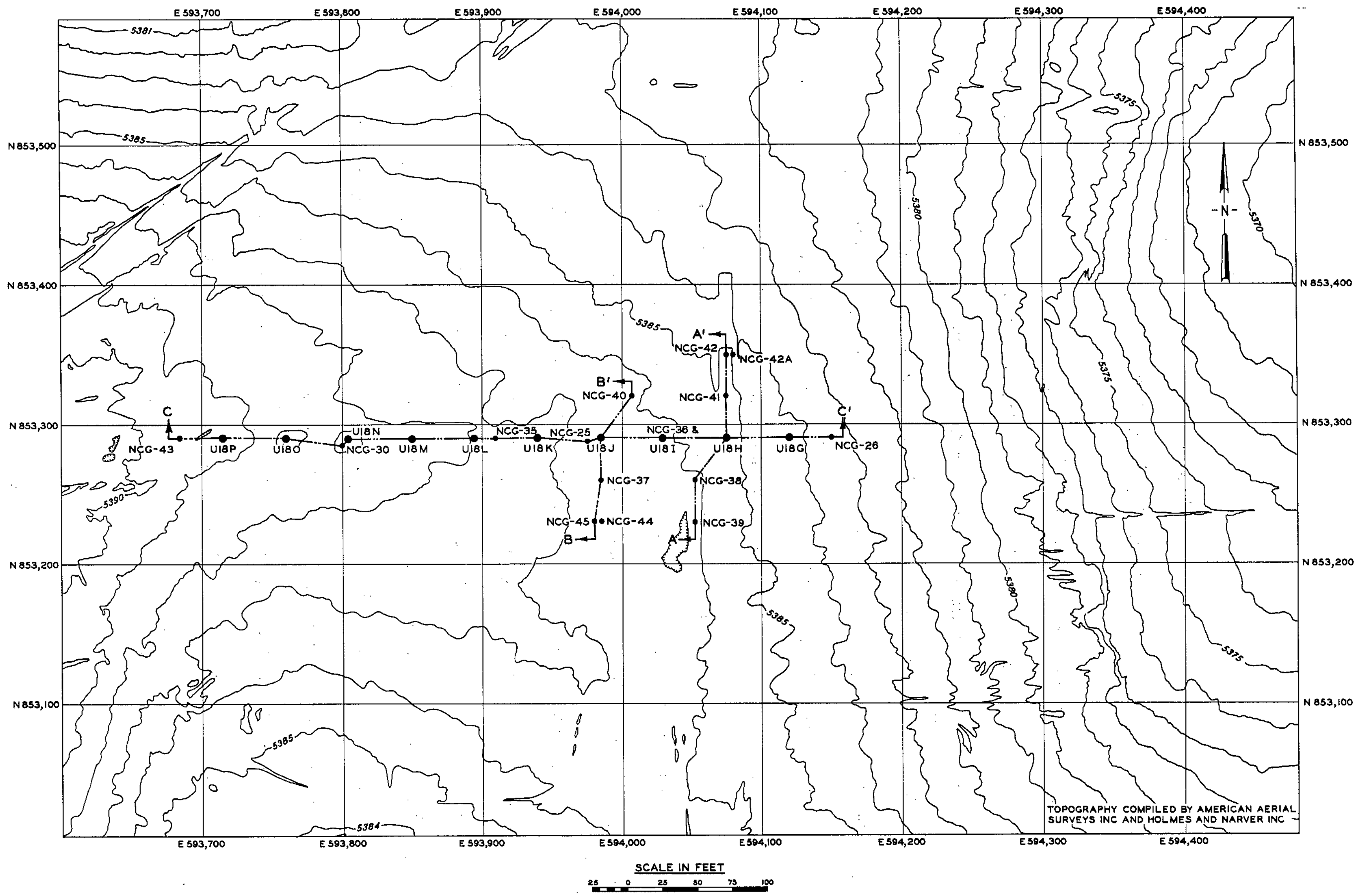


Figure 1.3 Preshot topography showing preshot boring and location of sections.

CHAPTER 2

PRESHOT CONDITIONS

2.1 GENERAL GEOLOGY AND PHYSIOGRAPHY

A relatively undissected sheet of basalt caps Buckboard Mesa and slopes gently south (Figure 1.2) from one or more fissure vents near the extinct Scrugham Peak cinder cone. The mesa is about 5.5 miles long and in the vicinity of the Dugout site about 1 mile across. The surface has a relief of about 100 feet between a medial sinuous ridge and the edge of the mesa. Most of the surface reflects the primary form of basaltic lava mantled only by a cover of windblown sandy silt.

Thickness of the basalt ranges from 100 feet near its edge to about 200 feet near the medial ridge. Locally the basalt sheet is a single thick lava flow, and the strata consist of vesicular basalt at the top, dense basalt in the middle, and a thin layer of vesicular basalt at the base. The entire flow is encased in a cindery clinker zone. Elsewhere, the basalt sheet consists of two or more lava tongues, each of which exhibits the same stratigraphy as the individual flows. These tongues are separated by a cindery vesicular zone that is characteristically oxidized to a reddish color. In some borings (Appendix A) three tongues are indicated by core-loss zones believed to be cindery, and it is quite possible that even more are present locally.

The implications of these observations are that most of the basalt sheet represents a single extrusive event, but that the lava spread from centrally situated feeder channels as relatively short tongues that advanced and then were overridden by later tongues.

The basalt outcrops along the mesa rim (Figure 2.1) where slopes of approximately 72 degrees (Reference 12) drop about 50 feet to gentler slopes on less resistant tuff breccia. Talus mantles much of the lower slopes. According to Reference 7 the groundwater table is 775 feet below the average elevation of the top of the mesa. The Dugout site is located on a topographic high branching to the east of the ridge of the mesa.

2.2 STRATIGRAPHY OF THE MEDIA

The principal media at the site are various types of basalt distinguished largely on the basis of vesicle content.

2.2.1 Soil. Borings at the Dugout site encountered from 2 to 14 feet of tan silty sand and sandy silt enclosing angular fragments of basalt. Fragments of basalt generally range from gravel size to blocks averaging 2 feet in greatest dimension. The silt was largely deposited by wind. Caliche impregnates a 1-foot layer immediately above top of rock, and calcium carbonate extends along joints for several feet into bedrock.

2.2.2 Basalt. The basalt cap at the Dugout site is about

180 feet thick. Boring NCG 36 penetrated the basalt to underlying tuffaceous sandstone and revealed the following sequence from top to bottom: a 90-foot flow, a 40-foot flow, and a 50-foot interval of vesicular basalt alternating with core-loss zones believed to be cinders. As presented in Figure 2.2, the lower zone consists of five thin flow tongues; however, it seems just as reasonable that the cindery core-loss zones are scattered pockets localized by quasi-turbulent flow in the base of a single lava flow.

Only the upper, 90-foot flow is of importance in this report in view of the fact that the cratering row charges lay at about 60 feet in depth. This flow is divisible into two units.

The upper vesicular basalt unit, which across the site averages approximately 40 feet in thickness, can be subdivided into three tabular subunits. These subunits are arranged in order of decreasing vesicularity from top to bottom. The highly vesicular basalt contains 20 percent or more of dispersed subspherical vesicles and corresponds to Type V basalt in Section 2.5 and Reference 13. A moderately vesicular basalt containing 10 to 20 percent of vesicles by volume flattened and arranged in discontinuous layers corresponds to Types III and IV basalt. A slightly vesicular basalt containing less than 10 percent of irregularly shaped vesicles in thin continuous layers corresponds to Type II basalt.

The lower, dense basalt contains no more than 2 percent of

dispersed vesicles and roughly corresponds to Type I basalt described in Section 2.5 and in Reference 13. Contacts between adjacent types and subtypes are gradational. The dense basalt varies in thickness but averages just over 50 feet (Appendixes A, B, and C) in the southern half of the site. Beneath the dense basalt is a layer of vesicular basalt about 1 foot thick.

2.3 PETROLOGY OF BASALT

According to References 2 and 15, the vesicular basalt on Buckboard Mesa is an olivine basalt, and the dense basalt is petrographically a subandesite (Reference 15). The two types are gradational, and any difference in composition may result from deuteric alteration.

In thin sections, the vesicular basalt consists of fine-grained, subhedral labradorite laths, with minor olivine and clinopyroxene phenocrysts, various opaque minerals, and products of devitrification.

The dense basalt is similar in mineralogical composition to the vesicular basalt except that the plagioclase is more sodic and somewhat coarser in grain size. Microscopic flow structure, which is prominent in the vesicular basalt, is less pronounced in dense basalt.

Chemical analyses of Buckboard Mesa basalt (Table 2.1) contributed by the U. S. Geological Survey reveal an unusual composition for a basalt, with moderately high silica content and high aluminum, potassium, and phosphorus contents. Chemically the rock might as

well be described as a trachy-andesite, a latite-basalt, or a potassium-rich andesitic basalt. Such potassium-rich basic lavas are scattered through the late Cenozoic strata of the Great Basin. Except for the oxidation state of iron, the composition is apparently very uniform in individual lava tongues and throughout the southern half of the mesa.

2.4 PRESHOT STRUCTURE OF BASALT

The internal structure of the basalt manifested as flow layers and joints is genetically and geometrically related to the mechanics of flow of the basalt while still hot.

2.4.1 Presentation of Structural Data. The reliability of structural orientations obtained by borehole camera in Buckboard Mesa basalt was critically investigated (References 11 and 12) for anomalous magnetism at the Sulky and Pre-Schooner sites, and it was found that readings are usually valid. A similar check at the Dugout site reveals only scattered magnetic anomalies. No structural orientations were recorded in the anomalous zones.

The orientations of all structural elements used in this report are represented for analysis in stereographic projection. Descriptions of the plotting technique can be found in most textbooks on structural geology (e.g. Reference 16). Planar elements are represented uniquely by their normals, and all projection is from the lower hemisphere to an equal area net.

2.4.2 Primary Flow Structure. During the late stage of lava flowage a prominent layering developed in the Buckboard Mesa basalt. This layering in part reflects the deformation of vesicles and is manifested best in the vesicular basalt containing moderate amounts of vesicles. Flow structure in dense basalt is also manifested as very faint, white crystalline layers.

In numerous exposures at the edge of the mesa the layered vesicular basalt is seen to typically sheathe a cylindrical core of dense basalt and in turn to be sheathed by a cylinder of highly vesicular and essentially isotropic basalt. An outer layer of basalt fragments (clinkers) encases the entire unit. Locally these concentric or nested cylinders (Reference 11) are visibly connected as lava toes or tongues to a broader feeder which in turn can be inferred from the topography to extend upslope to its junction with the broader main feeder centered at the medial ridge of the mesa. The Dugout site is situated near the crest of a subsidiary feeder (Figure 2.3).

For each photographed NX hole, it has been possible to measure several attitudes of flow layers of a single set, and locally two interpenetrating sets of flow layers are distinguishable (Figures 2.4, 2.5, and 2.6). The poles of these layers usually conform to great-circle distributions suggesting that the folding accompanying viscous flowage was essentially cylindroidal, i.e. about parallel linear fold axes at the scale considered. Many of the folds are

relatively minor wrinkles in the upper vesicular units, whereas others are portions of the large nested cylinders. The system in simplest form is orthogonal, with one set of horizontal folds paralleling the flow direction and the other set of horizontal cross folds at right angles. Generalized flow pattern, first recognized in the basalt at the Sulky site (Reference 11), can be constructed for the site (Figure 2.7). Off the center of a flow the system diverges from orthogonality, apparently as a consequence of viscous dragging and rotation of early folds by continued movement of the center of the mass. For this reason, the pattern is idealized; and at the sides where cross folds swing 90 degrees in strike and approach parallelism to flow direction, the pattern is not representative.

A truer representation of structure at the site is given in Figure 2.8, which summarizes some of the most extensive information in existence on the internal structure of a lava. The main feature to be noted is the set of recumbent fold axes which swing in trend more than 180 degrees and structurally outline a feeder channel within the upper basalt flow through which the molten lava at one time moved to the southeast. These axes are localized at a depth of about 60 feet. In a qualitative way these nested flow layer "surfaces" open to the upstream side vaguely suggesting confined laminar flow in a pipe; however, the comparison should not be carried too far at this time.

This feeder channel located at the south appears to cut and

modify by viscous drag an older channel to the north whose cylindrical structure trended north to northeast. Referring to Figure 2.7, one sees that the flow fold patterns for the two cylinders are similar despite the fact that the sense of flow was different by 90 degrees. As a result the site is characterized by an orthogonal structural grain. It will be seen below that major joints are conspicuously controlled by this structural pattern, and that subsequent deformation resulting from the blast is also influenced by the natural structural pattern.

Although such well-developed and complex structure is not generally common in basalt, complex forms of layering are almost always evident in more viscous lavas (e.g. see Reference 17) such as andesite, dacite, and latite. As noted in Section 2.3, the basalt has some mineralogical and chemical characteristics of an andesite, and this fact probably accounts for the abundant flow structure.

2.4.3 Terminology of Fractures and Fissures. Fractures encountered in samples or borings in cratering studies can be divided into three broad categories: drill breaks, blast fractures, and natural fractures (joints). Joints are distinguished from all others in this report by the presence of a natural, secondary coating. Fractures without coatings are broadly classed as fresh fractures where a finer distinction cannot be made. These may include blast fractures formed during the explosion or drill breaks formed during the coring

operation. Where only borehole photographic data are used, no drill breaks are involved.

For simplicity, the same terms are used in considering the open space, or fissure, created by a fracture; thus, the width of a fracture is the width of the opening along the fracture.

2.4.4 General Joint Orientation. The Buckboard Mesa basalt exhibits a well-developed system of thermal contraction joints that is geometrically related to the flow structure. This fact, documented at the Sulky site (Reference 11), is just as valid at other areas on the mesa. A tendency toward parallelism of joints and flow layers (Figure 2.9) has been verified at the Dugout site by measuring the angle between joints and nearby flow layers in inclined boring NCG 47. These joints tend to be subhorizontal in the upper 50 feet of the basalt, but Figure 2.10 indicates that the better correlation is with subhorizontal flow layers rather than the horizontal plane approximating the free surface of the basalt sheet. The reason for the preferred orientation of joints along or parallel to flow layers is simply that flow layers consist of tabular concentrations of vesicles which measurably reduce the effective area of rock over which a force acts.

In exposures along the rimrock, joints oriented perpendicular to flow layers are numerous. Figure 2.11 shows particularly well-developed systems of major steep joints arranged radially about the

cylinder axes of two terminal tongues of lava.

2.4.5 Cross Joints. Of the joints oriented perpendicular to flow layers, an important set consists of cross joints oriented normal to the major flow fold or cylinder axis in any given domain. The importance of this set was strongly emphasized in Reference 11, and the observations at the Dugout site verify this importance and clearly indicate that these major joints are probably the dominant natural structure utilized in the mechanism of crater formation on Buckboard Mesa (see Section 3.2.5).

A major steep joint was mapped in each of 8 of the 10 calyx holes (Appendix B). These 8 joints fall into 2 sets mutually perpendicular (Figure 2.8). Three in the eastern half of the site strike about N70W which is about normal to the axes of major recumbent folds of the early flow cylinder developed there. The five major joints mapped in the western half of the site strike about N30E, which is approximately normal to the axis of the late flow cylinder developed there.

The spacing of cross joints is clearly greater than the diameter of the calyx holes (3 feet). Photographs of the mesa rim (Figure 2.1) suggest that the spacing averages about 5 feet. The openings along cross joints are commonly an inch or greater in thickness.

2.4.6 Joint Frequency, Joint Spacing, and Lineal Joint Intercept Spacing. No exhaustive attempt has been made to determine true

spacing between adjacent joints of each of the sets at the site. A simpler parameter that has been measured in previous reports is termed in this report the lineal joint intercept spacing. This is the interval along a line between the intercepts of joints of any orientation. This information has been presented as joint frequency, i.e. the number of joint intercepts per unit interval of hole (Figure 2.12). A curve averaging out high and low values is superimposed. The cumulative frequency of lineal joint intercept spacings for the preshot vertical borings at the site is given in Figure 2.13 as an empirical index of degree of fracturing used previously at other craters. The median spacing is 0.9 foot.

The lineal joint intercept spacing measured along horizontal traverses in photographs of cliff walls at several stations along the mesa rim gave a mean value close to 3.0 feet (Reference 11). Average values of the same spacing parameter can be obtained from Figure 2.13 along vertical borings. The median vertical spacing is about 1 foot. These values suggest qualitatively that blocks isolated by natural joints tend to be tabular in the horizontal plane.

2.5 PHYSICAL PROPERTIES OF CORE SAMPLES

Thirty-eight NX core samples believed to be representative of various basalts at the Dugout site were tested by the WES Concrete Division for determination of physical properties.

Laboratory examinations indicate that the core samples of basalt can be grouped into five general types: Type I, dense; Type II, fairly dense with bands of vesicles; Type III, slightly vesicular with bands of vesicles; Type IV, slightly vesicular with uniformly distributed vesicles; and Type V, vesicular (Reference 13). It may be noted that the above classification differs slightly from the field classification used in other sections of this report. In general, Type I basalt corresponds to dense basalt with relatively few or no vesicles; Type II corresponds to vesicular basalt with less than 10 percent vesicles; Types III and IV correspond to vesicular basalt with 10 to 20 percent vesicles; and Type V corresponds to vesicular basalt with 20 percent or more vesicles.

2.5.1 Specific Gravity and Porosity. As can be seen in Tables 2.2 and 2.3, the dry bulk specific gravity of basalt ranged progressively from about 2.3 for Type V basalt to about 2.7 for Type I. The saturated surface-dry specific gravity varied from about 2.5 to 2.7. The specific gravity of solids averaged 2.85.

Porosity manifested in large part by megascopic vesicles ranged from as low as 2.4 percent for the dense Type I basalt to 18.7 percent for the highly vesicular Type V basalt (Table 2.2). The porosity was computed from the values of the dry bulk density and specific gravity of solids.

2.5.2 Static Strength of Intact Basalt. Unconfined compressive

strengths for six core samples from holes along the line of the row charge are presented in Table 2.2. The six strength values show no consistent correlation with rock type; however, in previous test results the intuitively expected tendency for ultimate strength to increase with decreasing vesicle content, i.e. toward Type I basalt, is clearly indicated. Tangent moduli of elasticity measured from the stress-strain curves of 10 unconfined samples from boring NCG 2.1 (Reference 13) ranged between 2.31×10^6 and 6.56×10^6 psi with no clear-cut correlation with rock type.

The data from 15 triaxial compression tests (Table 2.3 and Figure 2.14) were used to construct Mohr envelopes (Figure 2.15) and determine cohesion (c) and angle of internal friction (ϕ). No unconfined or tensile tests were performed; therefore, reliable values of the cohesion intercept at zero normal stress could not be determined. The ϕ values thus obtained were about 35 to 50 degrees for Type I basalt and about 20 degrees for Type V. The corresponding values of cohesion were 3,500 to 8,000 psi for Type I basalt and 3,500 psi for Type V basalt. These approximate values are only applicable in the range of confining pressure under which the triaxial tests were conducted.

The triaxial compression tests indicated that at confining pressures of 1,000 to 4,000 psi the vesicular Type V basalt had deviator stresses of about 12,000 to 13,000 psi, whereas dense

Type I basalt had much higher deviator stresses (in the range of 25,000 to 45,000 psi).

Double direct shear tests were performed on eight samples according to procedure CRD-C 90-64 outlined in Reference 18 except that sample size was 2-1/8 inches in diameter and 4-1/4 inches in length. The specimens were wrapped in polyethylene to prevent bond to the test blocks and to allow application of the normal (axial) pressure. The stress-strain curves are presented in Figure 2.16 and summarized in tabular form in Table 2.3. It can be seen that higher normal loads generally caused higher shear strengths, consistent within each sample group. Displacements at failure were in the range of 0.07 to 0.13 inch.

The values of shear strength determined at normal stresses of 1,000 to 4,000 psi fall near the envelopes representing the loci of the same parameter on the basis of triaxial compression tests (Figure 2.15). Tentatively, it appears that the two sources of shear strength data give values that roughly agree.

2.5.3 Static Strength of Jointed Samples. Triaxial compression tests were conducted on seven samples containing joints according to procedure CRD-C 93-64 of Reference 18. A piston having the same size as the specimen was used so that the applied load was equal to the major principal stress. One sample was Type V basalt, and the other six were dense basalt of Type I. The joint

in each case was inclined at about 65 degrees to the major principal plane. Displacements (Table 2.4) were measured between test plates of the testing machine with a dial gage. The relatively large early strains (Figure 2.17) occurred as the walls of the joint converged. Strains were computed by dividing the axial displacement by the initial specimen length. The axial displacements during the first slip were relatively consistent at 0.04 to 0.08 inch.

It can be seen (Table 2.4) that higher confining pressure usually yielded higher slip loads and ultimate loads. The sample from 57 to 58 feet in NCG 41 had much higher slip load and ultimate load apparently as a result of the healed condition of the joint. The relatively low ultimate load borne by the sample from 79 to 80 feet in NCG 45 in spite of a high confining pressure is most reasonably explained by the fact that the joint surface was relatively smooth.

<u>2.5.4 Dynamic Properties</u>. Samples of Types I and III basalt were tested by nondestructive methods to determine the dynamic properties of the intact rock (Table 2.5). The dynamic elastic properties, which include Poisson's ratio, modulus of elasticity, and modulus of rigidity, were determined from laboratory results which were inserted into formulas from the theory of vibrations. Test methods CRD-C 18 and CRD-C 51 in Reference 18 give the laboratory procedures for these tests. A discussion of the determination of dynamic Poisson's ratio is presented in Reference 19.

2.6 IN SITU PHYSICAL PROPERTIES

Mass properties of the media have been investigated by means of geophysical studies reported previously in References 20 and 21. A summary of Reference 21 is presented herein as Appendix D. Effective porosities and water loss coefficients were obtained from the preshot drilling program.

2.6.1 Velocities and Moduli Determined by Seismic and Vibratory Tests. One vibratory traverse (V-3) was made along a bearing east-southeast at a location about 500 feet south of the Dugout site, in the vicinity of borings NCG 21 through 24. Shear wave velocities determined by this technique are plotted versus depth in Figure 2.18. The velocity increases from approximately 250 ft/sec near the surface to 940 ft/sec at a depth of 10 feet and then gradually increases to 1,300 ft/sec at a depth of 26 feet. The break in curve slope at about 10 feet probably corresponds to the top of rock.

Shear and compression (Young's) moduli of elasticity calculated from the vibratory survey are plotted versus depth in Figure 2.19. Inasmuch as the area studied was rejected on the basis of poor core recovery indicating poor rock, the in situ moduli at the Dugout site, in excellent rock, are probably much higher.

The two seismic traverses (S-2 and S-3) indicated a compression wave velocity of 1,050 ft/sec for the near-surface materials

to a depth of about 5 feet. From 5 feet to about 16 feet the velocity increased to about 1,940 ft/sec, and below this the velocity continued to increase to about 4,000 ft/sec in vesicular basalt.

In postshot geophysical studies (Reference 21) at the Dugout site, a vibratory test was conducted at a distance of about 20 feet south of boring NCG 50, i.e. about 265 feet south of the row of charges. This was near the outer limit of material damaged by the blast, and thus essentially represents the preshot media. The tests showed that in situ shear wave velocity increased uniformly from about 400 ft/sec at about the 2-foot depth to about 2,500 ft/sec at the vesicular-dense basalt contact at a depth of about 42 feet. The velocity in dense basalt was 2,600 $\pm$ 100 ft/sec to a depth of about 140 feet, the limit of the tests.

2.6.2 Permeability as Approximated by Field Pressure Tests. The results of water pressure tests conducted in boring NCG 41 are presented in Figure 2.20. Tests were conducted in 5-foot vertical intervals sealed off by packers. The rate of flow was determined by measuring with a flowmeter the quantity of water pumped into the hole for a measured period of time, generally about 3 minutes, for two pump pressures.

The value of the water pressure tests lies in their use in evaluating the relative permeability of the deposit. If, for example, large quantities of water could be forced into a hole

section under small pressure, the indication is that the openings along joints of this section are relatively large. A water loss coefficient, P_i , may be expressed by the following formula (Reference 22):

$$P_i = \frac{Q}{Lh} \frac{\text{gal}}{(\text{min-ft-atmospheres})}$$

Where: Q = flow rate, gallons per minute

L = length of borehole test interval, feet

h = pressure at the midheight of the borehole interval, atmospheres

The water loss coefficient can be considered as an approximation of the coefficient of permeability.

2.6.3 Effective Porosity. Effective porosity, defined as that portion of porosity due to openings along fractures, was determined for two preshot borings, NCG 38 and 39.

The technique of estimation has been explained previously (References 11 and 12) and is not repeated here. Effective porosities for the two holes ranged from 0 to 20 percent (see Figure 3.13) when considered in 5-foot intervals, and the average was near 1 percent. This average compares with values of about 2 percent at the Sulky site and about 1 percent at the four Pre-Schooner sites.

TABLE 2.1 CHEMICAL CONTENTS, IN PERCENT BY WEIGHT, OF BASALT FROM BUCKBOARD MESA

Chemical analyses were made by P. L. D. Elmore, I. H. Barlow, S. D. Botts, and G. Chole of the U. S. Geological Survey, by methods similar to those described in USGS Bulletin 1036-G.

Sample No.	1	2	3	4	5[a]	R[b]
USGS Lab Number	156250	156251	156252	156253	156254	
Depth (feet)	6.3-6.8	24.8-25.5	56.5-57.0	96.6-97.3	111.0-111.6	
SiO_2	52.4	53.5	53.5	53.4	53.1	52.4-54.3
Al_2O_3	17.3	17.9	17.9	17.9	17.5	17.3-18.1
Fe_2O_3	2.2	4.2	2.9	2.6	3.1	2.2-7.1
FeO	6.0	3.6	4.9	5.0	5.1	1.0-6.0
MgO	5.4	4.4	4.9	4.7	5.1	4.0-5.4
CaO	6.8	6.9	6.7	7.1	6.6	6.6-7.1
Na_2O	3.9	4.2	4.2	4.2	4.1	3.9-4.2
K_2O	2.4	2.3	2.3	2.3	2.3	2.3-2.5
H_2O	0.77	0.63	0.42	0.65	0.52	0.35-0.78
TiO_2	1.4	1.5	1.5	1.5	1.5	1.4-1.5
P_2O_5	1.0	1.0	1.0	1.0	1.0	1.0-1.0
MnO	0.14	0.14	0.14	0.14	0.14	0.12-0.15
CO_2	0.08	<0.05	<0.05	0.12	<0.05	<0.05-0.12

[a] Samples 1-5 from Project Buckboard boring DB-4 at coordinates N 846,372 E 594,768.
[b] Range of composition of 14 analyzed samples including the 5 listed.

TABLE 2.2 GENERAL PROPERTIES OF BASALT FROM DUGOUT SITE

NCG Core Boring Number	Depth	Basalt Type	Bulk Specific Gravity		Specific Gravity of Solids	Porosity	Compressive Strength (Unconfined)
			Dry	SSD			
	feet					percent	psi
26	35.1-35.8	II	2.56	2.62	2.82	9.1	6,670
26	110.3-111.0	V	2.32	2.51	2.85	18.7	8,440
35	21.3-22.3	IV	2.38	2.48	2.92	18.5	8,180
35	39.0-40.5	III	2.52	2.61	2.91	13.2	--
35	74.7-75.9	I	2.67	2.71	2.83	5.5	--
36	32.1-32.9	IV	2.42	2.50	2.88	16.0	6,570
36	57.4-58.3	I	2.70	2.72	2.76	2.4	17,300
36	129.5-130.4	III	2.66	2.71	2.85	6.8	11,790

TABLE 2.3 RESULTS OF TRIAXIAL COMPRESSION AND DIRECT SHEAR TESTS

NCG Core Boring Number	Depth	Basalt Type	Dry Bulk Specific Gravity[a]	Triaxial Compressive Strength		Double Direct Shear Test Strength		
				Minor Principal Stress	Major Principal Stress	Normal Stress	Shear Strength	Displacement at Failure
	feet			psi	psi	psi	psi	inches
37	20.2-22.1	V	2.33	1,000	13,000	--	--	--
37	20.2-22.1	V	--	2,000	15,370	--	--	--
37	20.2-22.1	V	--	4,000	17,210	--	--	--
37	12.2-14.2	V	2.38	--	--	1,000	4,620	0.09
37	12.2-14.2	V	--	--	--	2,000	5,480	0.07
37	12.2-14.2	V	--	--	--	4,000	6,140	0.08
38	52.6-54.9	I	2.68	--	--	--	--	--
38	62.2-64.4	I	--	1,000	33,860	--	--	--
38	62.2-64.4	I	--	2,000	40,790	--	--	--
38	62.2-64.4	I	--	4,000	50,000	--	--	--
41	57.6-58.8	I	2.67	--	--	--	--	--
44	57.4-60.7	I	2.66	--	--	1,000	3,720	0.12
44	57.4-60.7	I	--	--	--	2,000	6,000	0.13
44	57.4-60.7	I	--	--	--	4,000	7,740	0.11
44	57.4-60.7	I	--	1,000	32,070	--	--	--
44	57.4-60.7	I	--	2,000	35,000	--	--	--
44	57.4-60.7	I	--	4,000	39,360	--	--	--
44	66.7-68.2	I	2.69	1,000	24,860	--	--	--
44	66.7-68.2	I	--	2,000	31,860	--	--	--
44	66.7-68.2	I	--	4,000	45,500	--	--	--
45	79.1-80.4	I	2.66	--	--	--	--	--
45	79.1-80.4	I	--	1,000	40,570	--	--	--
45	110.5-112.5	I	2.68	--	--	2,000	6,765	0.10
45	110.5-112.5	I	--	--	--	4,000	10,570	0.11
45	110.5-112.5	I	--	1,000	33,070	--	--	--
45	110.5-112.5	I	--	2,000	41,500	--	--	--

[a] $\dfrac{\text{Weight of oven dry materials in grams}}{\text{Volume computed from measurements in cubic centimeters}}$.

TABLE 2.4 RESULTS OF TRIAXIAL COMPRESSION TESTS ON SAMPLES CONTAINING A JOINT

NCG Core Boring Number	Depth	Basalt Type	Minor Principal Stress	Relative Joint Roughness	Joint Angle[a]	Load at First Slip	Axial Displacement at First Slip	Major Principal Stress at Failure	Total Axial Displacement	Dimension of Toe Cut[b]	
										Top	Bottom
	feet		psi		degrees	1,000 lb	inches	1,000 lb	inches	inches	inches
37	20.2-22.1	V	2,000	high	65	30	0.08	32	0.31	0.50	0.50
38	52.6-54.9	I	500	high	65	11	0.04	21	0.40	0	0
38	52.6-54.9	I	1,500	medium	65	20	0.06	32	0.21	0	0.25
41	57.6-58.8	I	3,000	healed	65	80	0.08	80	0.08	0.25	0.50
44	57.4-60.7	I	1,000	medium	59	20	0.04	44	0.36	0	0
44	66.7-68.2	I	2,000	medium	60	28	0.08	53	0.58	0.50	0.25
45	79.1-80.4	I	4,000	low	68	28	0.07	46	0.57	0.50	0.40

[a] Angle between joint and horizontal, i.e. the complement of angle between the joint and the direction of the major principal stress.

[b] Height of wedge cut from side of sample adjacent to joint to keep side from contacting the opposite test plate during testing. Actual bearing surface of joint is therefore somewhat reduced.

TABLE 2.5 DYNAMIC PHYSICAL PROPERTIES OF ROCK CORES

Depth[a]	Basalt Type	Dynamic Young's Modulus, Using		Modulus of Rigidity, Using Torsional Frequency	Compression Wave Velocity V_c	Dynamic Poisson's Ratio, Using		
		Transverse Frequency	Longitudinal Frequency			Velocity V_c and Longitudinal Frequency	Transverse and Torsional Frequencies	Longitudinal and Torsional Frequencies
feet		10^6 psi	10^6 psi	10^6 psi	ft/sec			
39.5-40.5	III	3.63[b]	4.58	1.91	13,260	0.29	-0.05[b]	0.20
74.7-75.9	I	8.16	7.87	3.16	16,255	0.26	0.29	0.25

[a] Samples from boring NCG 35.
[b] About 10 percent vesicles probably caused low transverse frequency and resulted in low values of other parameters computed from transverse frequency.

Figure 2.1 Rim of Buckboard Mesa at Photo Station 4 (N 845,200 E 594,600). Boards hanging from cliffs at top and bottom are 10 feet long.

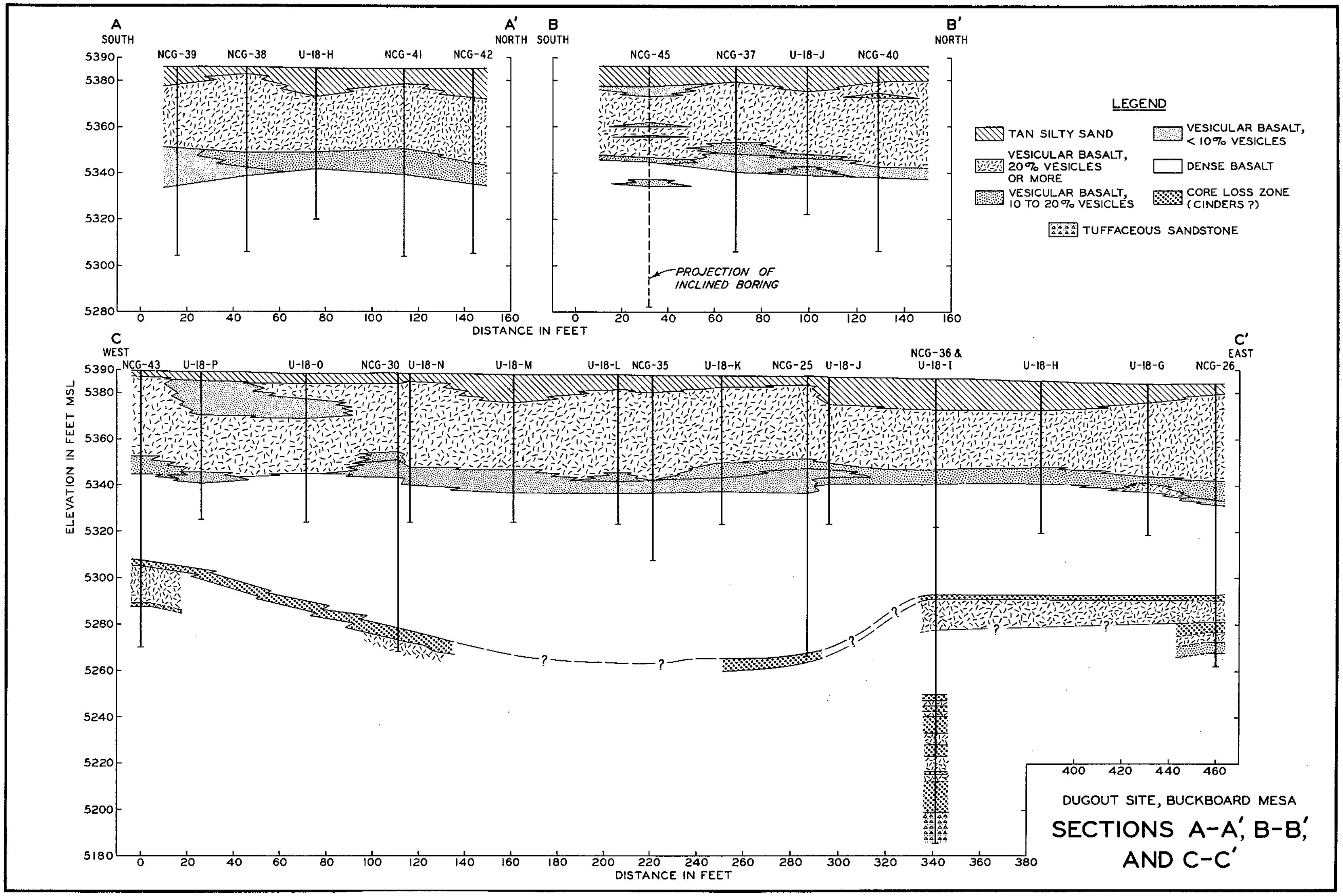


Figure 2.2 Stratigraphic cross sections of Dugout site. Location of sections shown in Figure 1.3.

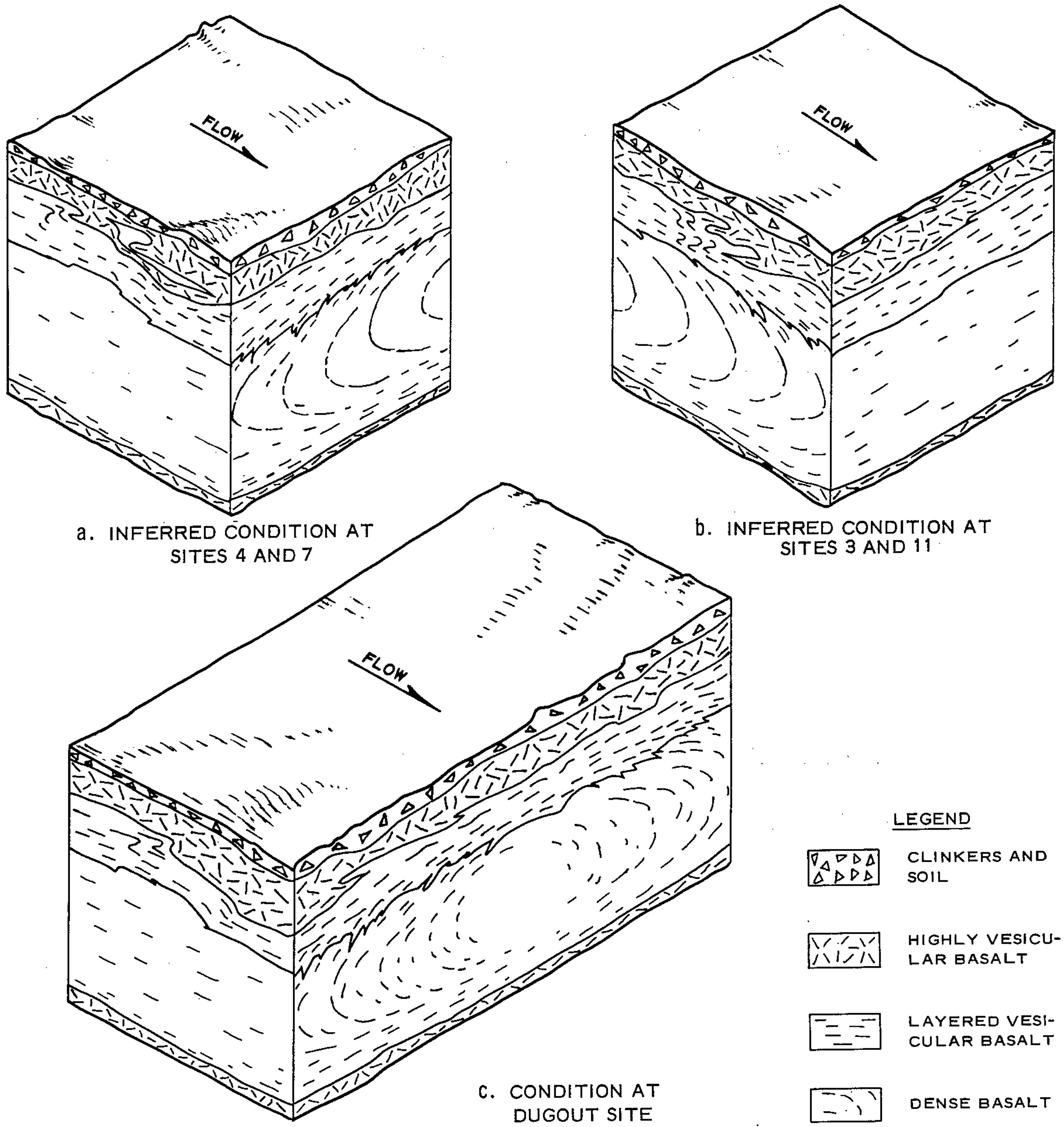


Figure 2.3 Semi-schematic block diagrams of cylindrical internal structure of major basalt tongues in vicinity of Pre-Schooner and Dugout sites.

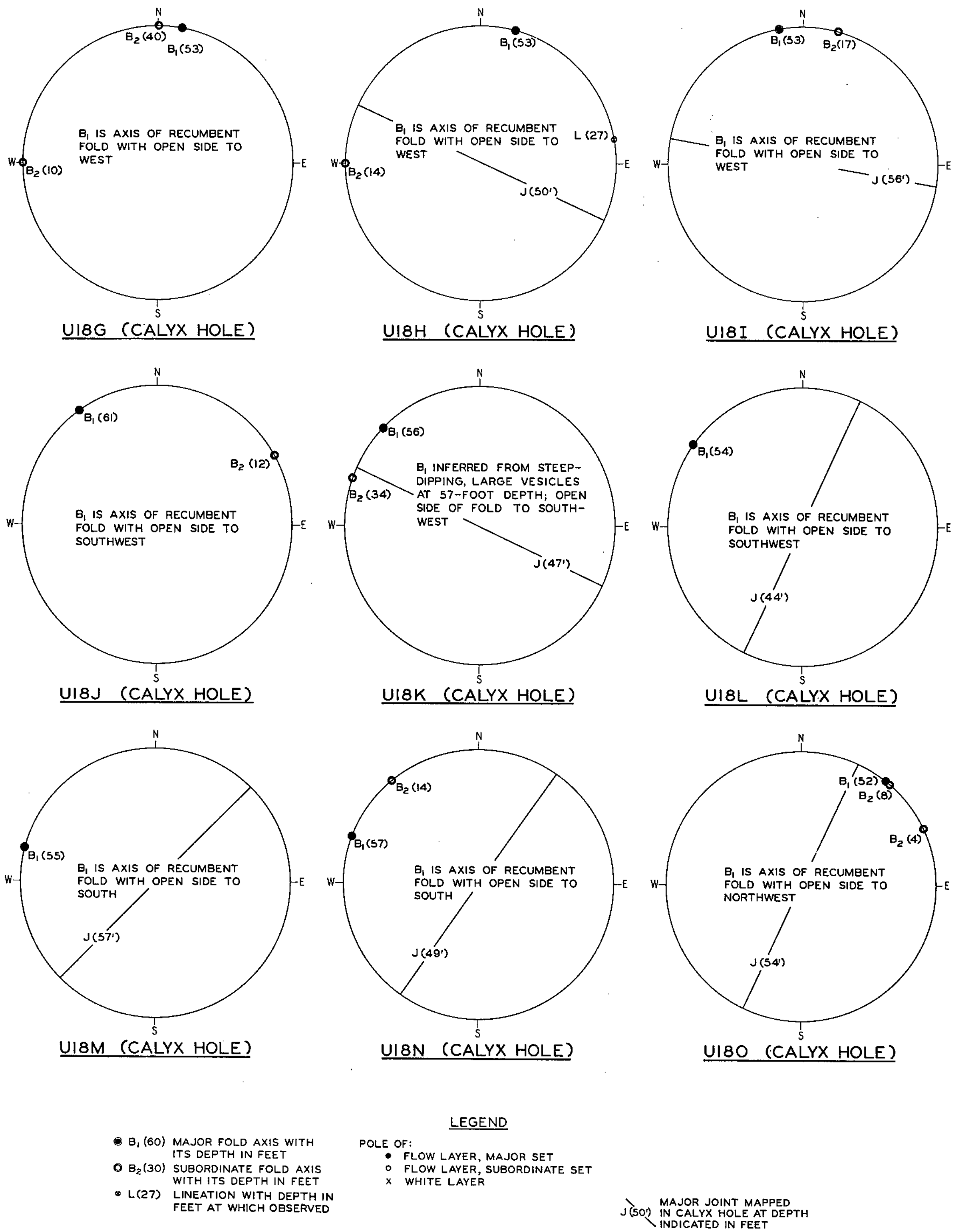


Figure 2.4 Flow structure and major joint orientations in calyx borings.

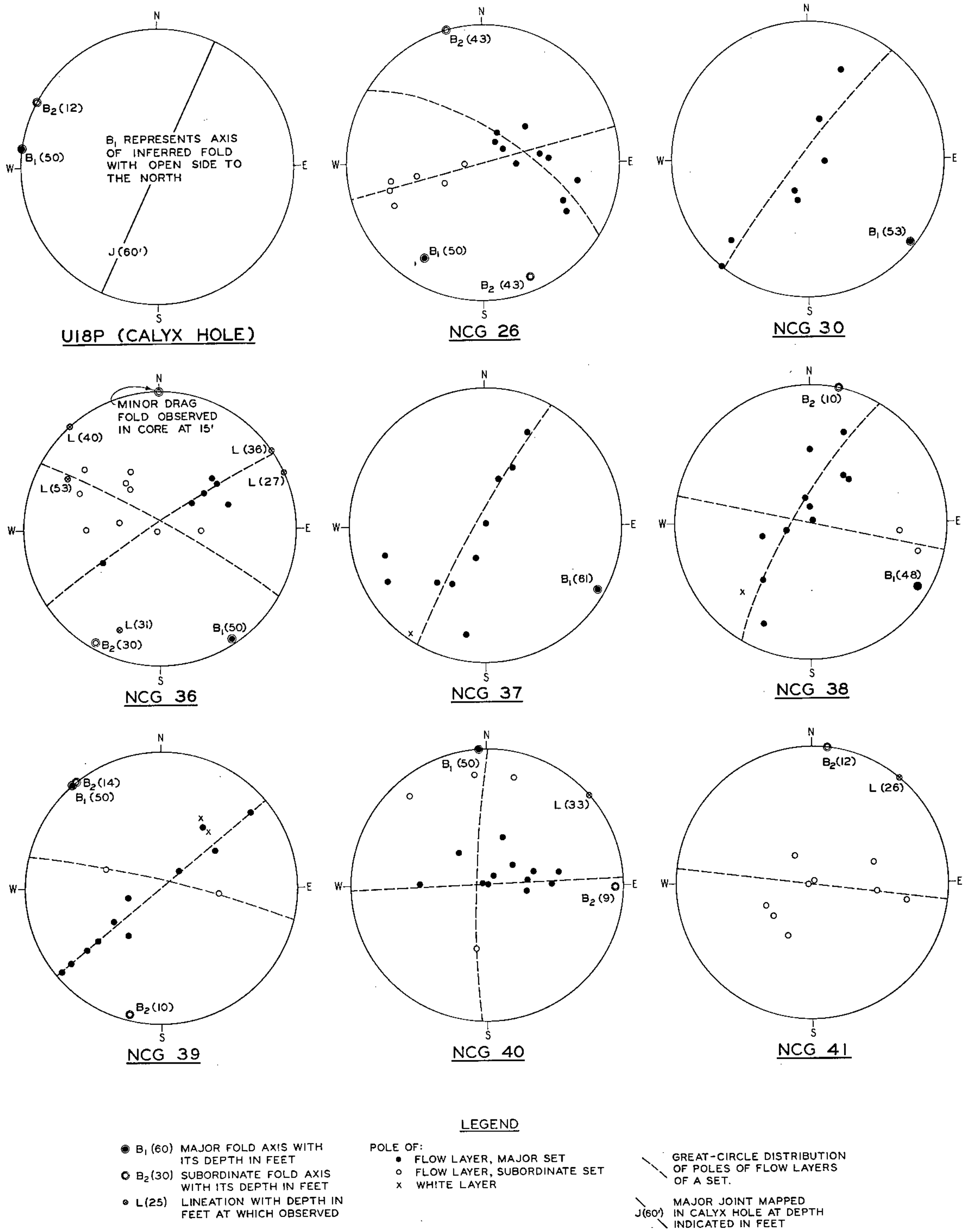


Figure 2.5 Flow structure and major joint orientations in borings.

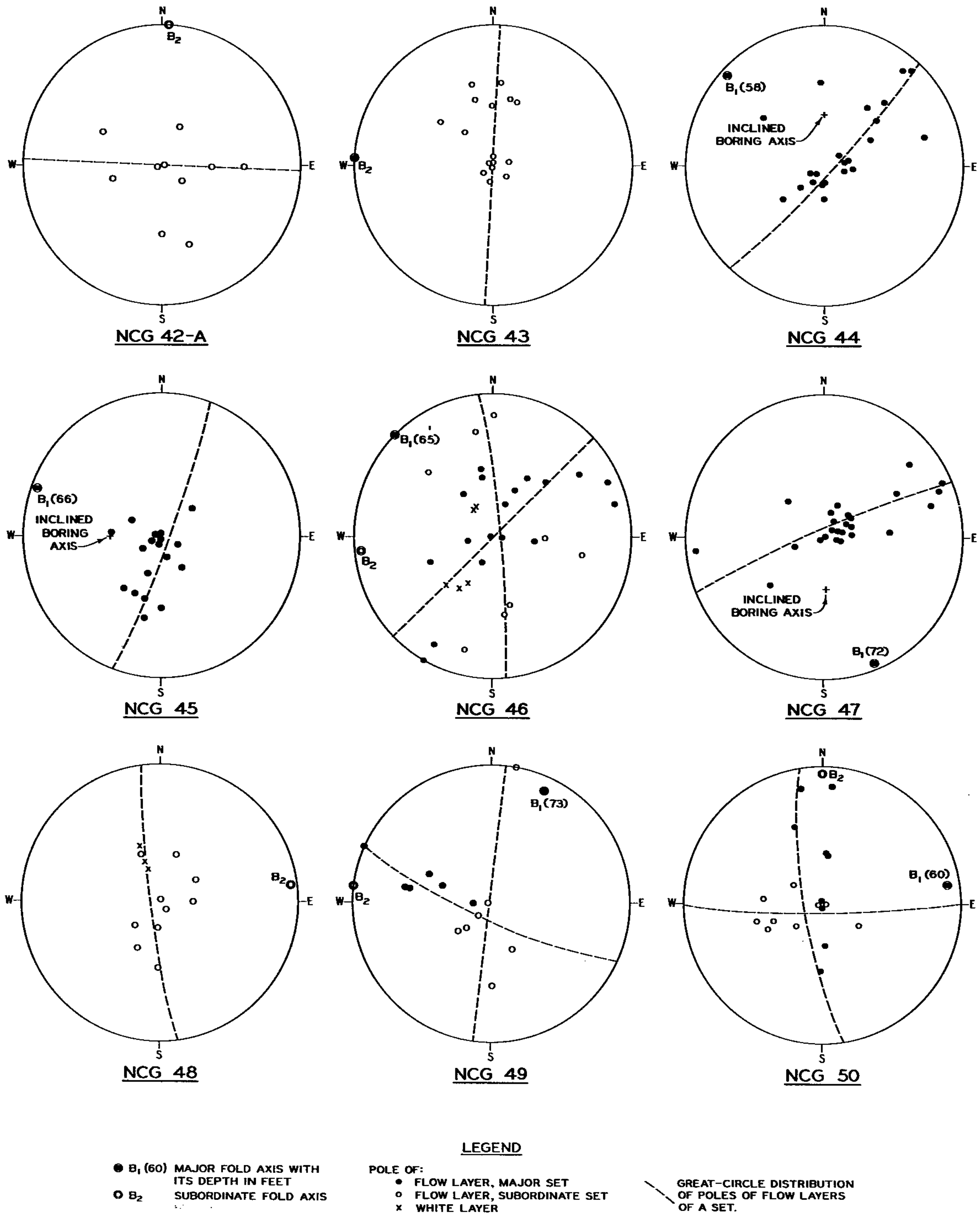


Figure 2.6 Flow structure orientations in borings.

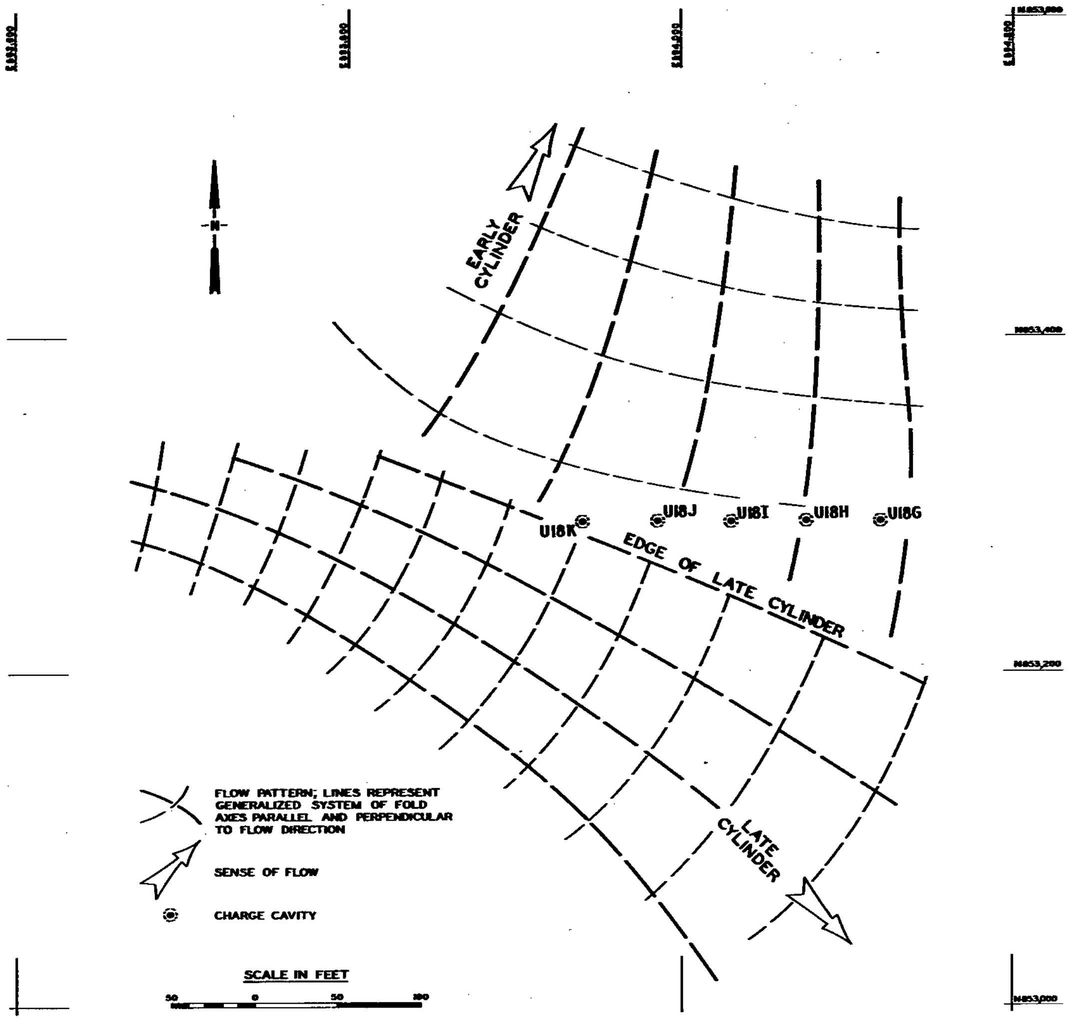


Figure 2.7 Primary flow structure pattern of basalt.

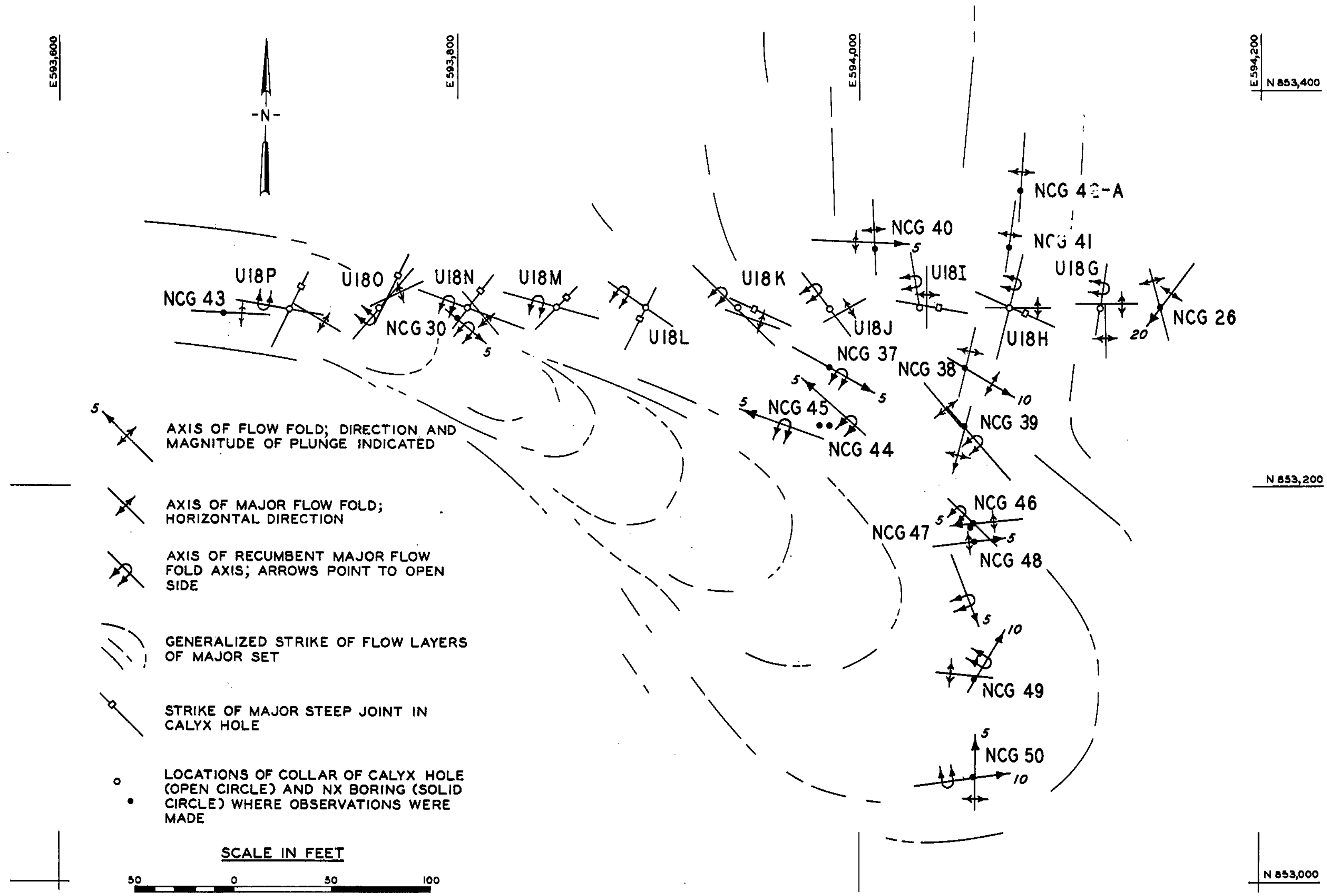
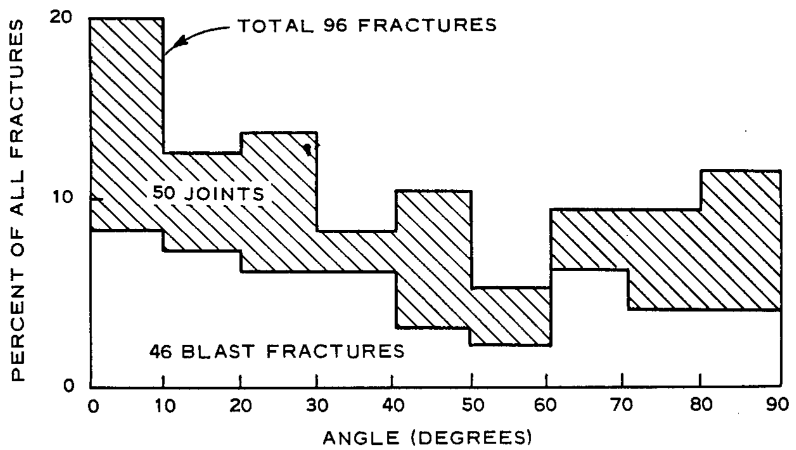
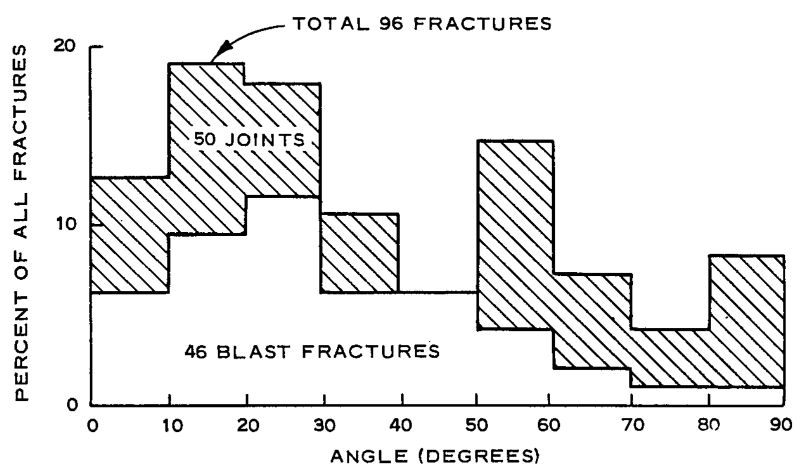


Figure 2.8 Geological structure of the basalt at the Dugout site.

Figure 2.9 Platy jointing resulting from preferred orientation of joints parallel and perpendicular to flow layering.



A. ANGLE BETWEEN FRACTURE AND NEARBY FLOW LAYER



B. ANGLE BETWEEN FRACTURE AND HORIZONTAL PLANE

Figure 2.10 Angular relation between all fractures and flow layers or horizontal plane (NCG 47). Total subdivided into joints and blast fractures.

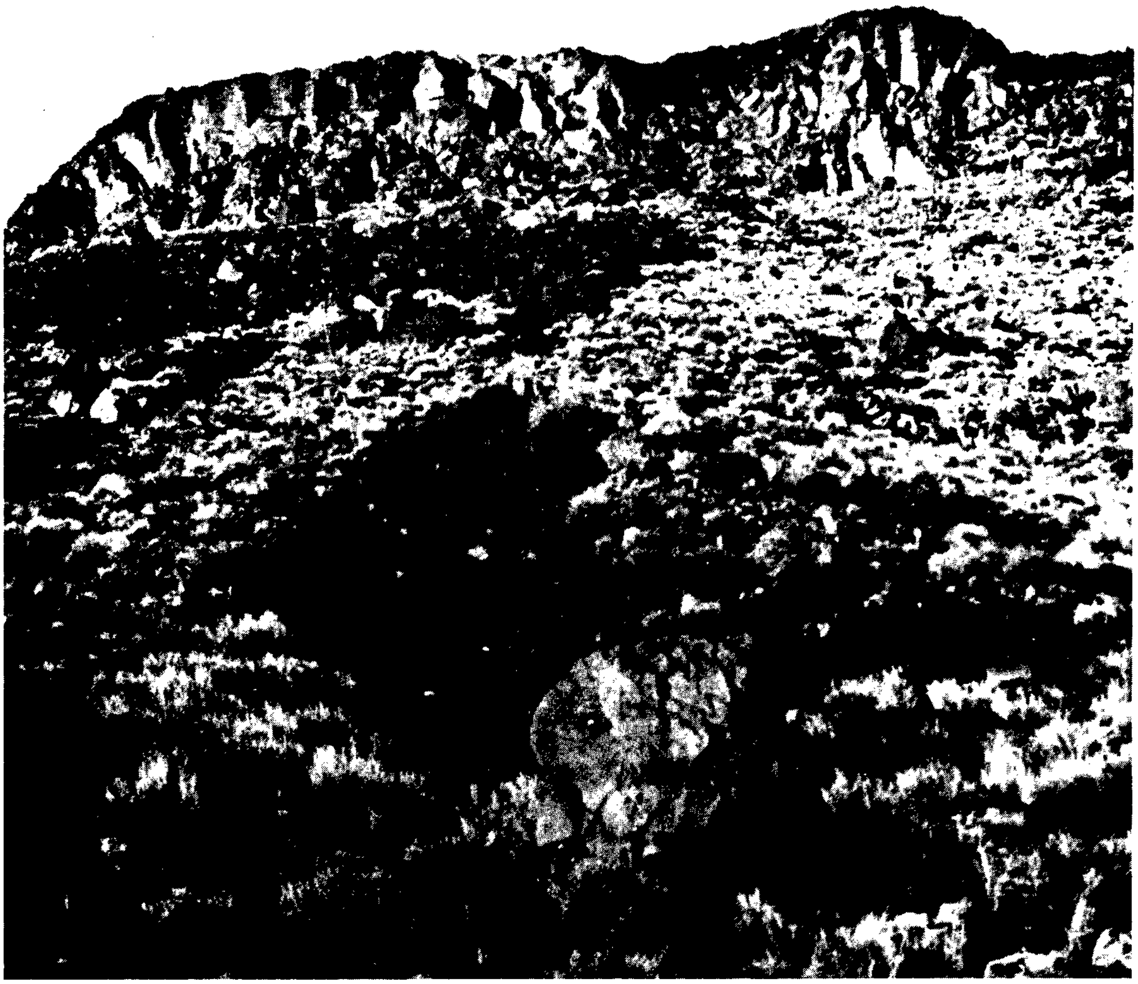


Figure 2.11 Two terminal lava tongues at mesa rim showing radial arrangement of major joints. Talus extends from cliffs to foreground.

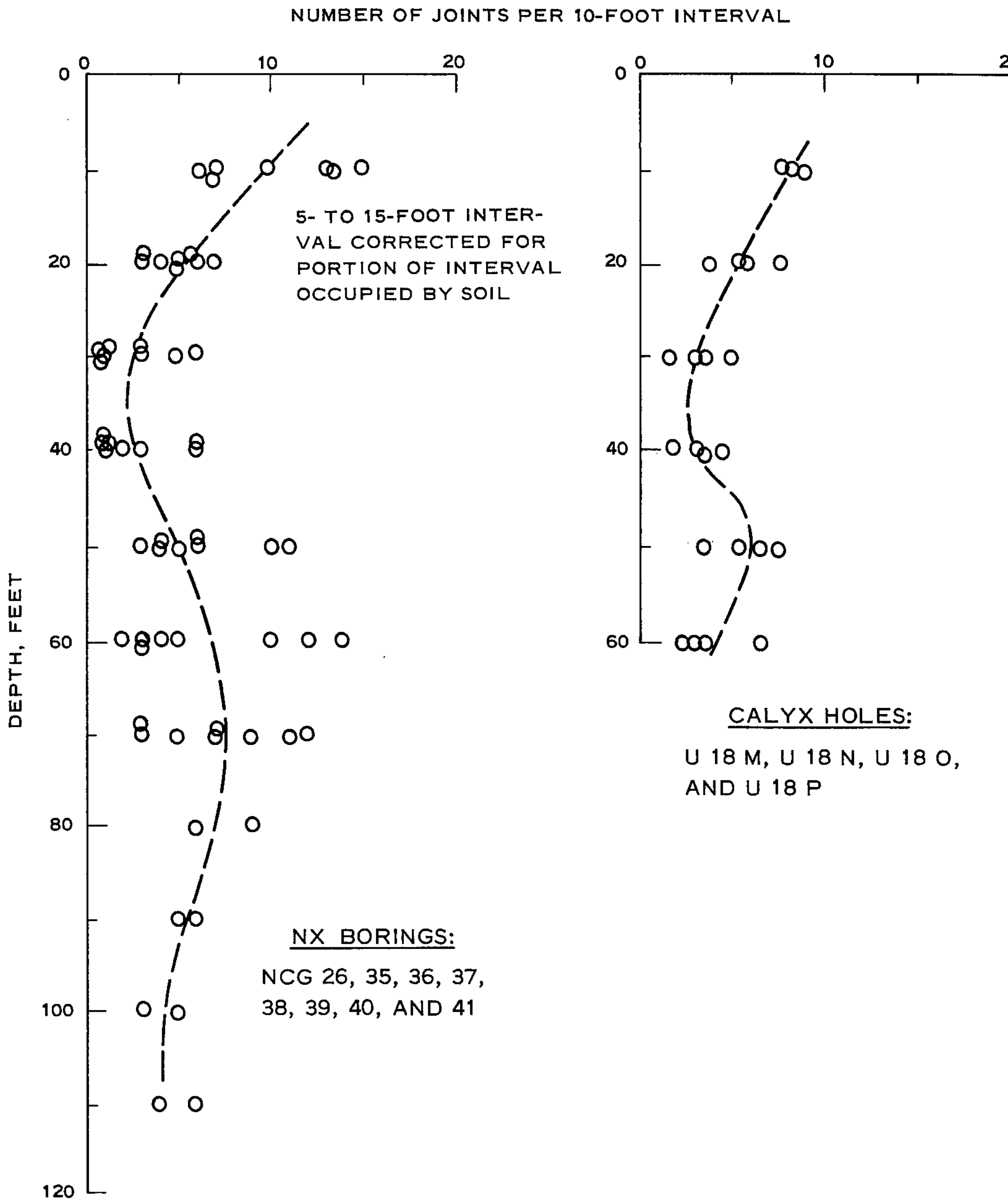


Figure 2.12 Natural joint frequency in vertical holes.

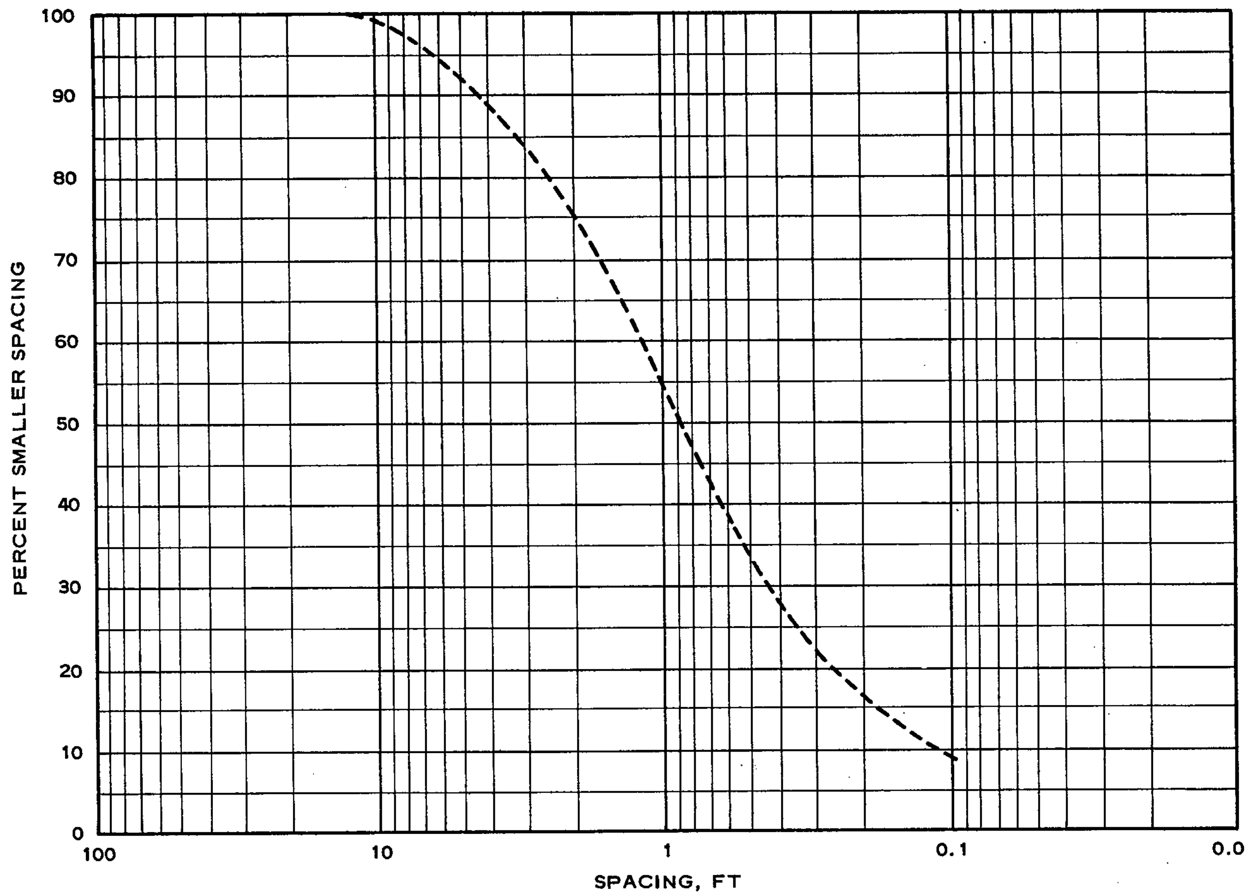


Figure 2.13 Cumulative frequency of 475 lineal joint intercept spacings in preshot vertical borings.

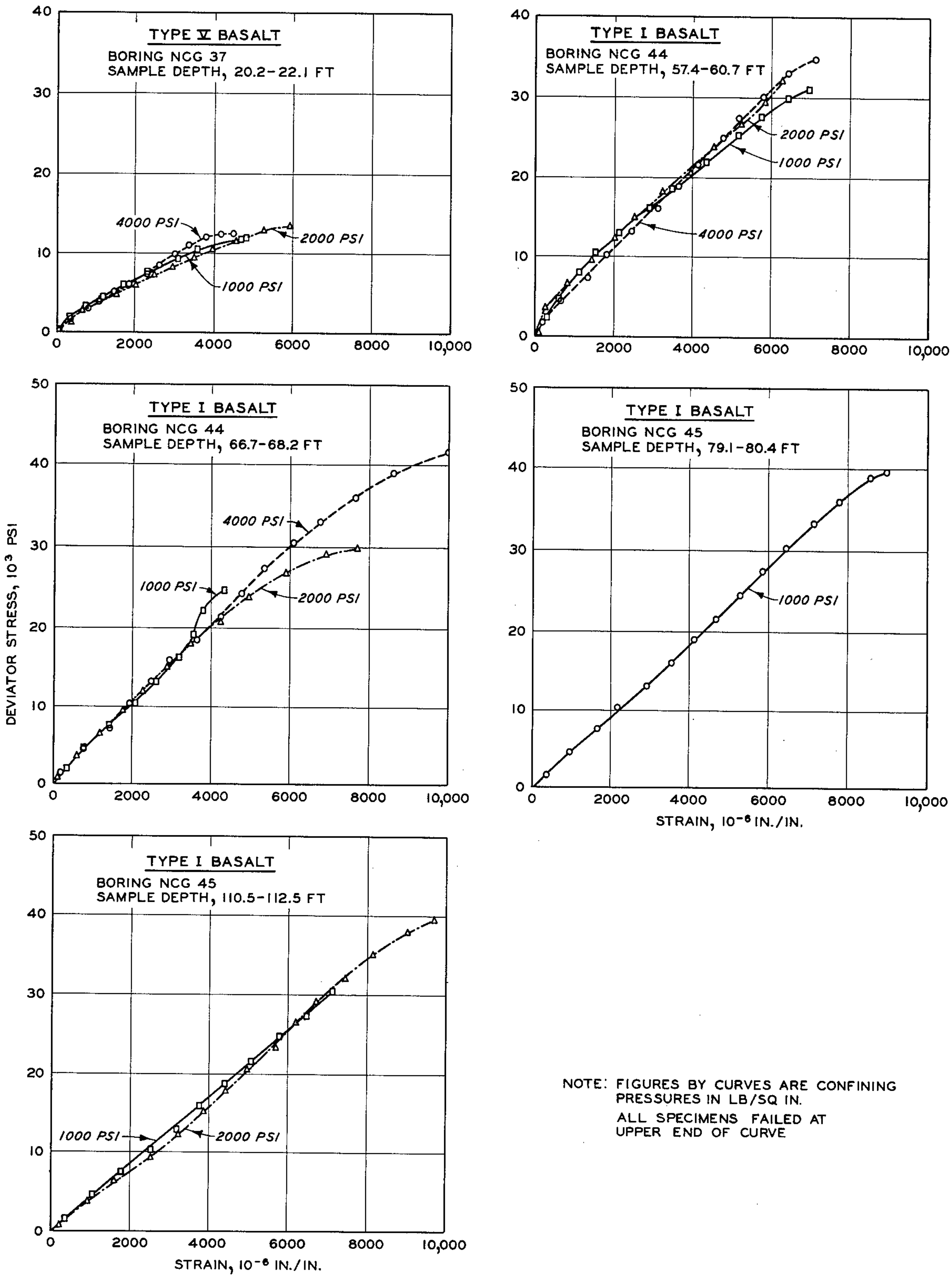


Figure 2.14 Selected triaxial compression test stress-strain curves.

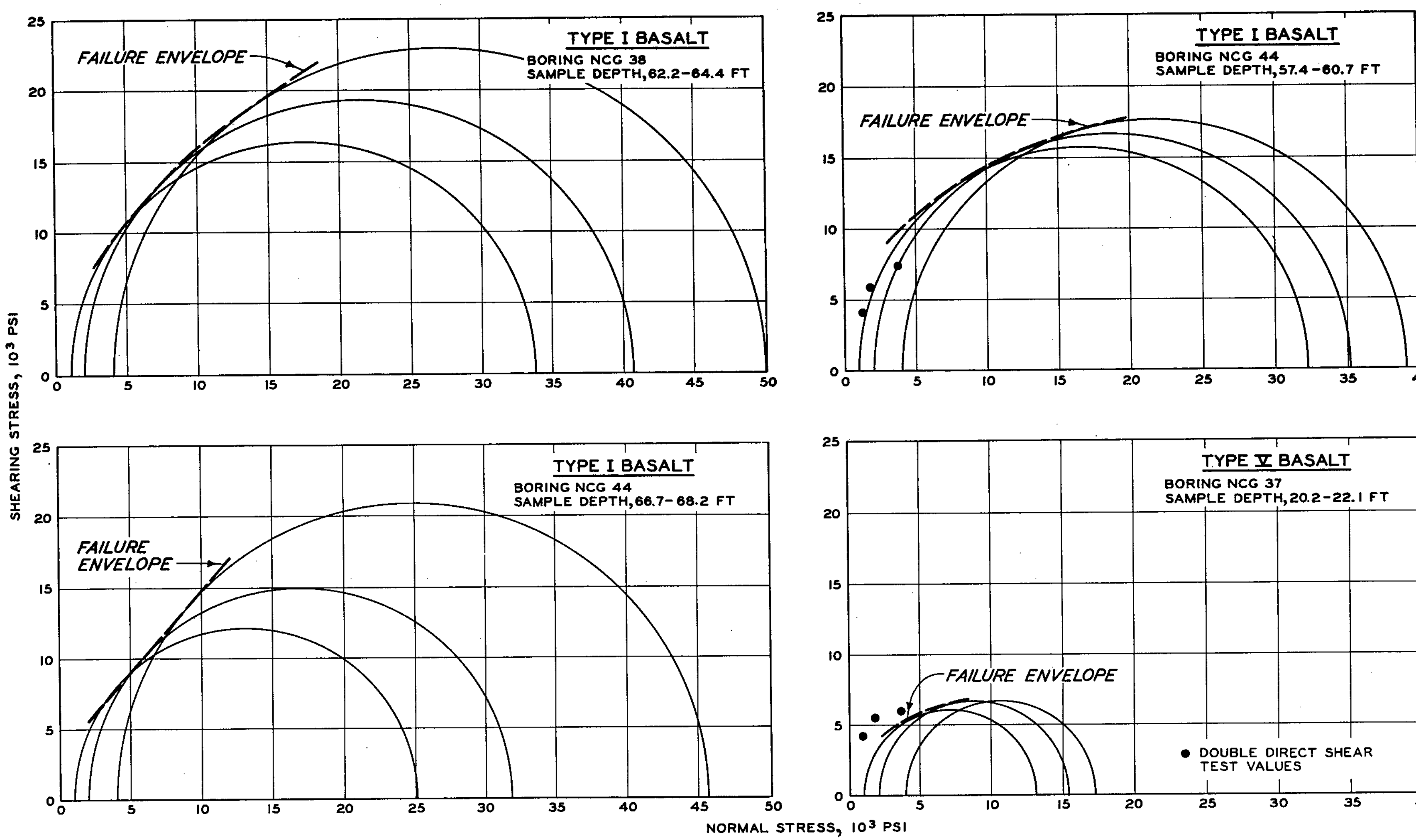


Figure 2.15 Mohr's failure envelopes for groups of basalt samples.

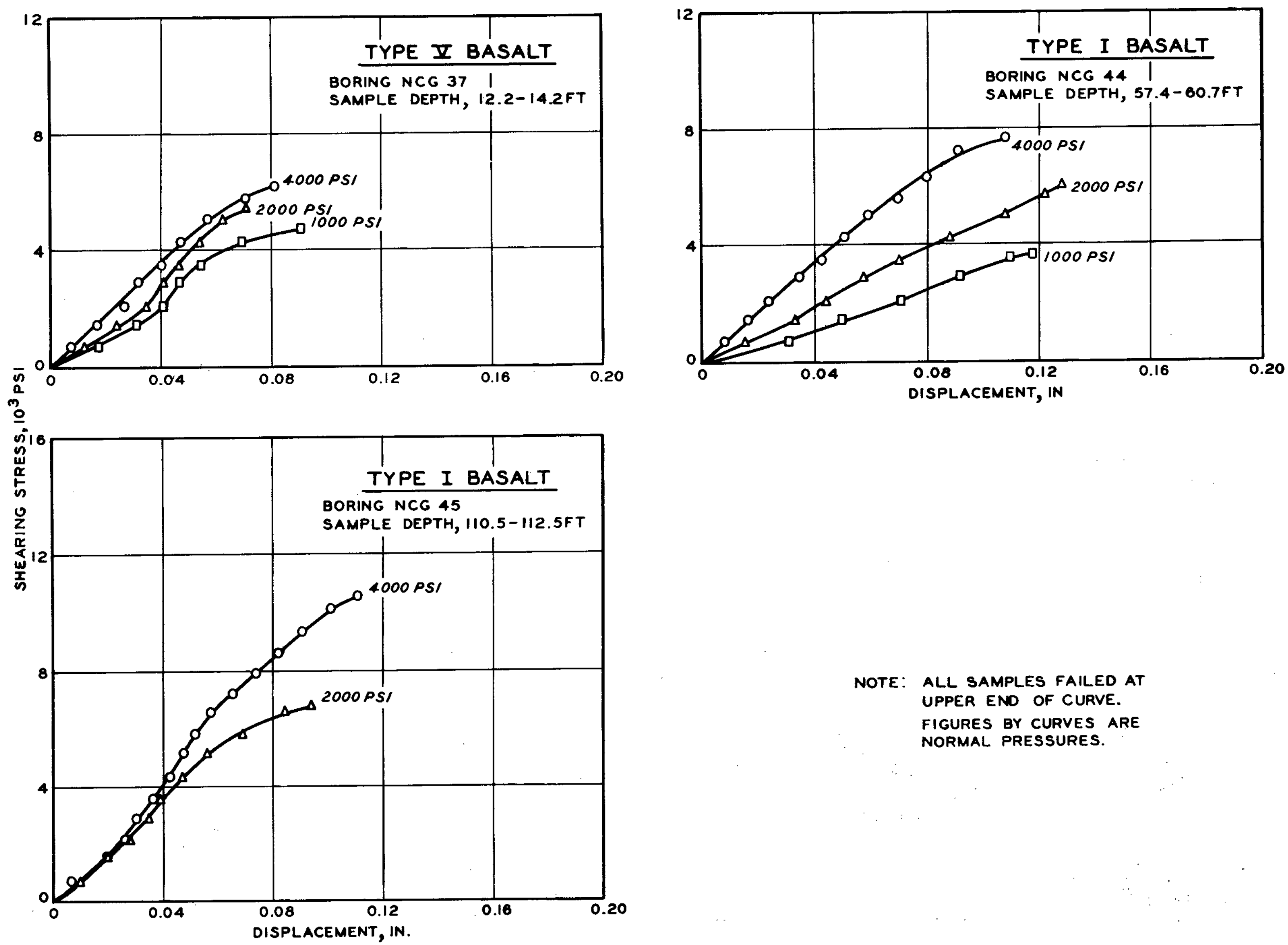


Figure 2.16 Shear stress versus displacement curves for double direct shear tests.

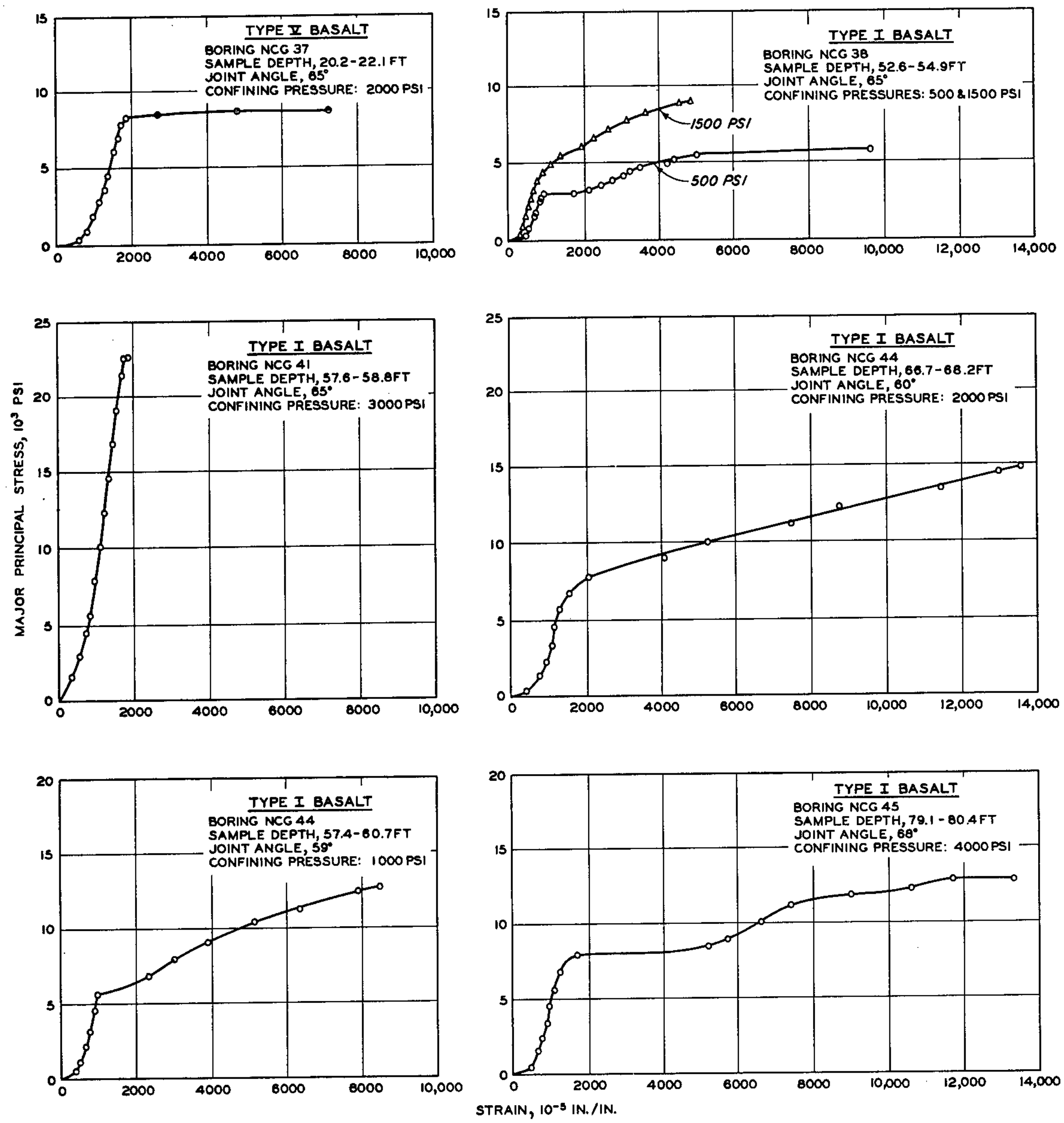


Figure 2.17 Stress-strain curves of jointed basalt samples tested in triaxial compression.

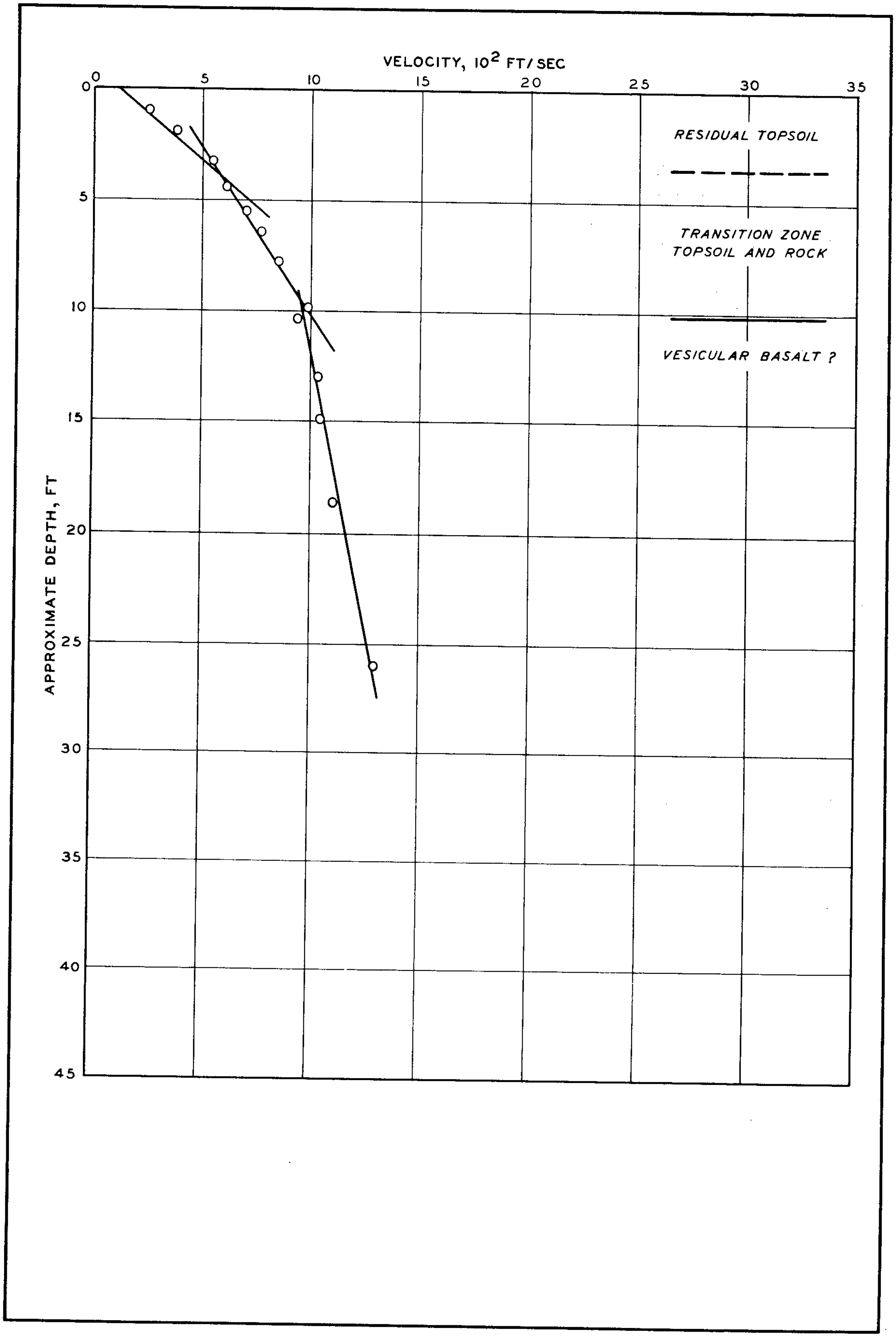


Figure 2.18 Shear wave velocity versus depth along traverse V-3 as determined by the vibratory method.

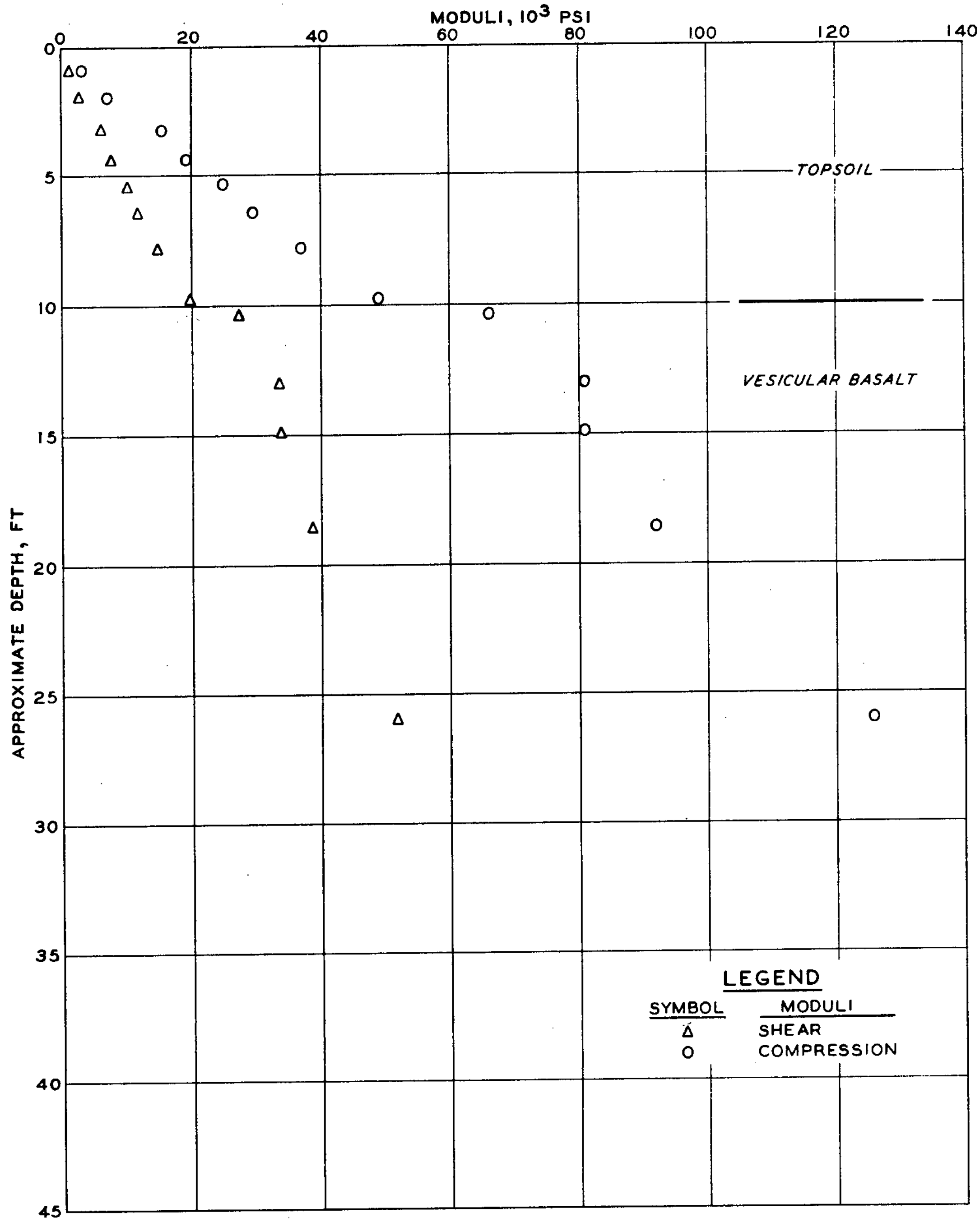


Figure 2.19 Moduli versus depth along vibrator traverse V-3.

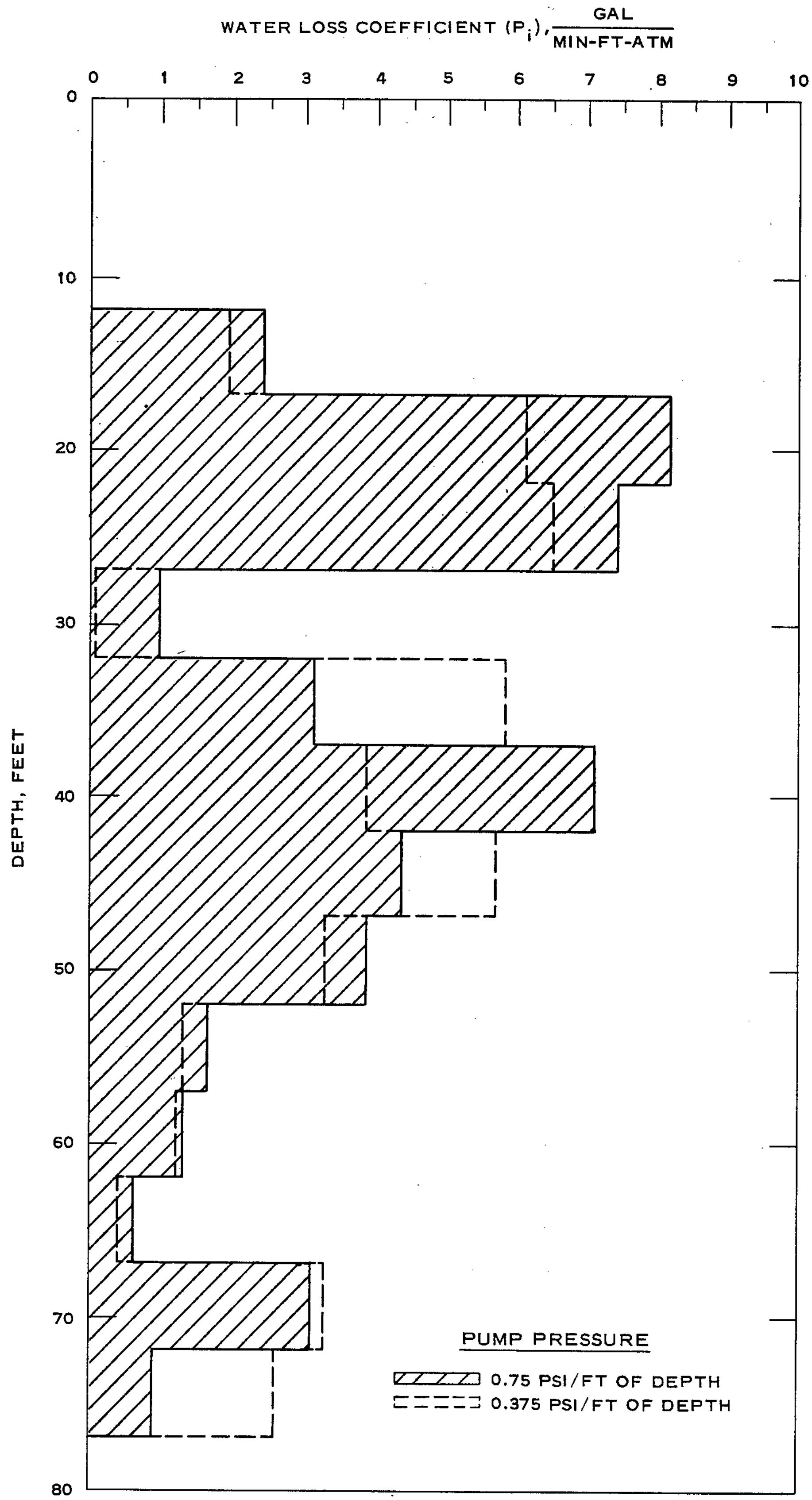


Figure 2.20 Results of water pressure tests in Boring NCG 41.

CHAPTER 3

POSTSHOT CONDITIONS AND EFFECTS OF BLAST

The row charge was detonated at 0806 PDT on 24 June 1964, and it produced an apparent crater about 135 feet wide, 285 feet long, and 35 feet deep (Figures 3.1 and 3.2).

Postshot geological engineering studies included trenching and examination of two traverses through the lip. One of these trenches was extended to explore the true crater. Bulk density of ejecta was determined by mechanical analysis of a large sample excavated from one trench. Five NX core borings were drilled (Table 3.1) along the projection of one trench to outline zones of disturbance adjacent to the true crater. Borehole photographs provided information on fracture frequency and orientation. The four sand-filled calyx holes that survived the blast were evacuated of sand, and their walls were mapped for comparison with preshot conditions.

The size distribution of the ejecta was analyzed by methods using postshot aerial photographs of the entire site and closeup photographs along traverses across the crater lip and into the fallback within the crater.

3.1 MODIFICATION OF SURFACE

The crater dimensions and surface conditions at the Dugout site described in References 23 and 24 are summarized below

along with results of the current study.

3.1.1 Apparent Crater. The apparent crater can be divided into a linear portion and the two end portions. Dimensions are with regard to the preshot position of the ground surface as datum. The central linear portion averages 136 feet in width (Figure 3.2) and 35.2 feet in depth. The greatest depth of 41.7 feet is located 31.4 feet west of the preshot position of the central charge hole (U18I). The total length of the crater is 287 feet.

The north lip along the linear portion averages about 24.6 feet in height above the preshot position of the ground surface and the south lip averages about 22.8 feet. The lip on the ends is much lower, being only about 12 and 14 feet on west and east ends, respectively.

3.1.2 Displaced Ground Surface. The lip uplift, defined as the permanent vertical displacement of the preshot ground surface, reaches at least as great as 12 feet (Figure 3.3). Two profiles exposed during the excavation of the south trench (Reference 24) revealed maximum lip uplifts of 10 and 3 feet along north-south lines only 8 feet apart. The displaced ground surface is apparently quite irregular, probably as a consequence of strong influence by the joints in the basalt (Reference 24). Along the west trench at the end of the crater the displaced ground surface is only about 2 feet above the preshot position (Figure 3.4).

3.1.3 Ejecta and Fallback Distribution. Fallback and ejecta generally decrease in thickness outward. Thickness of fallback near the center of the crater is estimated to be about 35 feet. On the linear sides of the crater the ejecta just outside the lip crest is of the order of 20 feet thick. On the end portions of the crater the ejecta is only about half as thick, i.e. about 10 feet. Outward from the lip the ejecta blanket thins to a limit of continuous cover (other than dust) at about 500 and 370 feet, north and south, respectively, and 200 feet off the ends of the row charge. It is of some interest that the continuous ejecta extends about 40 percent farther to the north than to the south. Grain size also decreases outward generally. The distribution of particular combinations of grain size classes is shown in Figure 3.5. This map was prepared from a gridded aerial photograph of the crater and vicinity in a manner similar to that described in Section 3.1.4. No conspicuous departures from a symmetry conforming to the charge configuration are evident.

3.1.4 Ejecta and Fallback Grain Size. The particle size distribution of the ejecta and fallback was obtained by analyzing overlapping photographs taken along traverses across the lip (Figure 3.6). In this method a 10- by 10-foot ground surface with a string grid superimposed was photographed, and later the size of the grain under each of the 100 intersection points was measured on the

photograph. The 100 grains thus give an approximation of the overall grain size as percent of the area.

Areal percent abundance of each size class is then converted to volume percent, and this in turn is approximately equal to weight percent when it is realized that the basalt does not have an excessive range of unit weight. It is also assumed that grain size does not vary uniformly with depth.

The cumulative frequency of grain size averaged for each of four traverses outward from the crater lip is shown in Figure 3.7. Three of these traverses have curves that are clustered together while the fourth, along the S20E line, is coarser in grain size. No conspicuously coarser ejecta were revealed in this area by the analysis of the aerial photographs of the entire site. Two photo traverses were also made from the center of the crater along lines due north and south.

Cumulative frequency curves at 15 stations on the north line fall within the range indicated in Figure 3.8. These curves do not indicate a consistent trend of changing grain size outward from the crater center, but a slight outward decrease does become apparent when a twofold division of all grain size data is made at Station 1+00 roughly on the apparent lip crest. Thus, it is seen that fall-back is slightly coarser than ejecta though the two curves cross at their coarser ends. Similarly, nine grain size curves that were

used to establish the range (Figure 3.8) along the south traverse show no persistent trend of decreasing size outward. An outward decrease in grain size does appear, however, when data are lumped into fallback and ejecta nearer than or beyond Station 1+00 on the lip crest.

3.1.5 Bulk Density of Ejecta Obtained by Mechanical Analysis. A large volume of ejecta excavated from the south trench (Figure 3.2) has been analyzed to determine the bulk density and the bulking factor (Reference 24). Material was excavated by front-end loaders and removed to scales where it was weighed by the truckload. Volume was obtained by surveying grid points over the sample area before and after excavation and determining thickness of sample by the difference in elevations. Accuracy of the grid layout and leveling was to the nearest 0.1 foot. Particular care was taken to keep the bottom of the sample above the buried displaced ground surface.

The top of the trapezoidal-shaped sample was of the order of 40 feet wide and 120 feet long, and the thickness was about 8 feet. This sample extended south from near the apparent lip crest and thus was all ejecta.

According to Reference 24, 29,462 cubic feet of ejecta weighing 3,509,070 pounds were excavated. This sample had a bulk density of 119 pcf (compared to about 165 pcf in situ) and a bulking factor

of 1.39. A bulking factor of about 1.65 was obtained from similar samples at the Delta and Charlie craters.

3.2 DISTURBANCE OF BASALT IN SUBSURFACE

Various degrees of fracturing and permanent deformation of basalt have been recognized from analyses of the five postshot borings, the two lip trenches, and the four calyx holes that survived the blast. These data provide radial cross sections in southward and westward directions from ZP. Supplemental postshot geophysical investigations are described in Appendix D.

As in previous reports the rupture zone adjacent to the true crater has been subdivided into a blast-fractured zone and a bulked zone with the two partly superimposed. In this report a third subdivision of the rupture zone has been distinguished. This zone, characterized by permanent shear deformation, may be the equivalent of the "plastic zone" in previous, idealized crater mechanics terminology.

3.2.1 True Crater. The true crater was exposed to about two-thirds of its depth along the south trench (Figure 3.9). The surface is approximately paraboloidal in shape with an upper slope of about 48 degrees. This upper portion of the true crater coincided with the apparent crater in places with only minor fallback. Below the trench the true crater can be projected to a depth of about 70 feet.

The true crater at preshot ground elevation is about 80 feet horizontal distance from the projection of the row charge in the south trench. In the west trench, in keeping with the different conditions in the end portions of the crater, the true crater at the preshot ground elevation is about 57 feet from the end of the row charge (Figure 3.4). Projected from here to the vicinity of the ZP the true crater wall at the end of the crater slopes about 54 degrees (Figure 3.10).

<u>3.2.2 Blast-Fractured Zone</u>. Blast fractures were inferred in borehole photographs and locally verified in core and surviving calyx hole walls. Blast fracture frequency along the four tape lines used for orientation in mapping the calyx hole was averaged, whereas in the NX core borings only a single line was available for counting. The frequency of blast fractures per 10-foot interval of hole has been plotted against depth of the interval below the surface (Figure 3.9), and smooth simple curves fitted to these data can be used to obtain values representing average conditions at various points in the cross section. Both vertical holes and an inclined hole are used in contouring this blast effect along the south section so that a slight variation in frequency due to orientation of the sampling lines is involved.

Both the west section and the south section (Figures 3.9 and 3.10) reveal an outward decrease in blast fractures. Much as the

shallow and surficial effects, the blast fractures extend farther to the sides of the linear section of the crater than from its end portions. The best estimation of a limit of significant blast fracturing is about 250 feet from the line of charges on the south and about 160 feet from the end of the row charge on the west.

A different method of obtaining the blast fracture envelope has been used in Figure 3.11. Here a background of average number of natural joints in preshot holes (Figure 2.12) has been assumed to represent the site media and has been subtracted from total natural joints and blast fractures to approximate blast fracture distribution indirectly. No judgment in identifying blast fractures is required.

The blast-fractured zone flares toward the surface, except at a depth of 60 feet where the zone extends beyond this idealized limit. A similar shape exists at the Delta crater (Reference 12). No explanation is definitely established at this time, but it seems probable that the protuberance in the blast-fractured zone correlates with differences in physical properties manifested near the zone containing flow-layered vesicular basalt, or perhaps that it is inherent in the mechanics of cratering in rock.

<u>3.2.3 Orientation of Blast Fractures</u>. The orientations of blast fractures, natural joints, and flow structures measured in boring NCG 47 are compared in Figure 3.12, and the geometric

relation is clarified in Figure 2.10. This relation has been established in References 11 and 12, and only a brief comparison is presented to assure the reader that the same condition exists at the Dugout site. In Figure 2.10A, it can be seen that both joints and blast fractures have a preferred orientation paralleling flow layers. A weaker tendency for joints to be oriented perpendicular to flow layers is also suggested. Part B of the same figure indicates that the tendency for fractures to be gently dipping is fortuitous, i.e. neither the horizontal plane nor the top of the basalt, which is nearly horizontal, governs the orientation of fractures.

3.2.4 Bulked Zone. A zone in which the effective porosity of basalt has been changed by the blast (Figure 3.13) can be outlined in the south cross section. It is characterized by increasing effective porosity toward the ZP from insignificant change at about 260 feet from the ZP to about 3 percent at a distance of 120 feet from the ZP. The effective porosity probably exceeds 10 percent near the true crater.

As with the zone of blast fracturing, the bulked zone departs from a flared shape by extending farther from ZP at the level of the highly flow-layered vesicular basalt. Again it is not clear whether this is an effect of stratigraphic layering or possibly is inherent in the mechanics of cratering.

3.2.5 Zone of Shear Deformation in Surviving Calyx Holes.

The five calyx holes, situated along the westward projection of the line of charges, had been filled with sand, and subsequent to the detonation, four of these were cleaned out and examined for deformation. The hole nearest the charges, U18L, was never located. Details of the postshot conditions are incorporated in the calyx hole logs in Appendix B. Measurements of preshot and postshot distances between reference points set in the walls before the blast are presented in Tables 3.2 through 3.5. Differences in preshot and postshot diameters indicate that the basalt has experienced strain of a magnitude of as much as a few percent in the calyx holes. Measurements made for this study with precision of thousandths of an inch indicate a decrease of the east-west dimension and an increase of the north-south dimension in three of the holes.

Hole diameters recorded continuously by a specially designed caliper moving along the hole have been reported in Reference 25. The accuracy of this method is lower than that attained by measuring between reference points. Nevertheless, preshot and postshot dimensions obtained with the moving calipers supplement those between reference points. The caliper measurements were most valuable in U18M and U18N where they provided strain components across northeast and northwest diameters. In hole U18M, nearest

the crater, the northeast-southwest diameter has been decreased by about 0.8 inch and the northwest-southeast diameter has been increased by 0.4 inch, i.e. strains of about -2.2 and +1.1 percent, respectively. These combined with strains of +1.5 and -0.8 percent along north-south and east-west diameters, respectively, indicate that the deformation was not symmetrically related to the force vector from the nearest ZP. This same asymmetry, as illustrated in Figure 3.14, is also manifested in U18N although the magnitude of strain measured by the two methods is not in agreement and combined results are little more than qualitative.

Average positive strains along the north-south dimension of holes U18M, U18N, and U18P are 1.5, 0.08, and 0.019 percent, respectively, at distances of 90, 135, and 225 feet from the nearest charge, U18K. Negative strains, i.e. decreases in hole dimensions, during the blast probably result in part from irreversible random motion of rock blocks into the sand-filled hole, and they are considered to have little value in analyzing strain of the basalt. No significant positive strain in north-south direction was measured in U18O. Disregarding U18O, the average positive strains decrease nonlinearly with distance from the nearest charge. These measured permanent north-south strains are within an order of magnitude of peak east-west strains calculated from accelerations and velocities measured by instruments in the bottoms of the calyx holes

(Table 3.1 in Reference 25). Calculated values converted to percent are 0.54, 0.09, and 0.05 percent, respectively. It should be emphasized that the calculations were simplified to fit elastic theory. In actuality the agreement between calculated peak strains and observed residual strains indicates that most displacement is permanent.

Probably most of this deformation in the horizontal plane results from slip along steep joints such as has been mapped in the postshot condition (Appendix B). Thus, at depths of 23 feet in U18M and 50 feet in U18N, the northwest wall along a major vertical joint striking northeast has moved 1 inch and 1/8 inch northeastward with respect to the southeast wall.

The force responsible for the deformation is assumed to be the compressive pulse of the initial shock wave propagated westward from the nearest ZP. A shear component in the observed sense is to be expected on steep planes striking northeast if the least principal stress is also in the horizontal plane. Where such planes are already in existence as a well-developed set of major joints, most of the horizontal deformation takes place by shear along these surfaces.

3.2.6 Zone of Spreading Revealed in Upper Part of Calyx Hole U18M. Calyx hole U18M is offset along flat fractures at four places in its upper half (Appendix B). The upper side has been

displaced toward the crater relative to the lower side of each fracture. The magnitude of the offset is almost 3 inches on the upper fracture. Clearly the significant shear displacement in the opposite direction of what might have been expected warrants careful consideration. Points within this upper portion of the rupture zone at one instant in its development were offset, with respect to those immediately below, toward the crater.

According to the usage in this report, movements with respect to the adjacent material are termed relative movements, whereas movements with respect to preshot positions are termed net movements.

Some indication of a net craterward movement is found in Figure 3.4 where the displaced ground surface within 12 feet of the lip of the true crater is largely below its preshot position. The 4-foot depression in the displaced ground surface located over a large fissure exposed in the bottom of the trench suggests that the section to the left has moved toward the crater leaving a gap behind. Another large, steep fissure is also present farther to the left.

No such net craterward movement or reverse offset is evident in the south trench map (Figure 3.3). The displaced ground surface climbs uniformly to a high of about 12 feet above preshot position at the true lip crest, and the only evidence of significant

shear deformation is where a mass of broken basalt and the overlying soil zone has been displaced upward and outward from the crater center.

3.2.7 Anomalous Magnetism. Ten of the 18 NX borings at the Dugout site that were photographed had intervals in which the borehole camera compass needle varied erratically from a normal orientation. These intervals apparently penetrated portions of the basalt where unusually strong magnetic fields discordant to the earth's field prevailed.

At the Sulky site, these zones seemed to be present only in postshot borings, and it was suggested (Reference 11) that the anomalous fields resulted from the blast. Investigations at the Delta crater (Reference 12) seemed to support this, though two weak anomalies had also been present at about the same depth in the preshot condition. The anomalous zones at the Dugout site listed in Table 3.6 are present in about the same percentage of preshot holes as of postshot holes. Thus, there is little or no support at the Dugout site for the suggestion that the anomalies are piezomagnetic effects of the blast. Instead they would appear to be a natural phenomenon.

TABLE 3.1 SUMMARY OF POSTSHOT SUBSURFACE INVESTIGATIONS

NCG Core Boring Number	Coordinates[a]		Ground Elevation	Total Depth	Core Recovery	Type of Boring	Angle of Boring	Borehole Camera Log
			feet msl	feet	pct		degrees	interval, feet
46	N 853,180	E 594,057	5,387.12	139.5	86.8	NX	Vertical	2.0 to 118.0
47	N 853,177	E 594,056	5,387.20	115.9	95.1	NX	60 South	2.0 to 114.0
48	N 853,170	E 594,057	5,387.12	120.0	95.1	NX	Vertical	3.0 to 116.0
49	N 853,100	E 594,057	5,385.82	79.8	94.0	NX	Vertical	3.0 to 75.0
50	N 853,050	E 594,057	5,387.37	80.0	97.3	NX	Vertical	5.0 to 75.0

[a] Nevada state coordinate system.

TABLE 3.2 PRESHOT AND POSTSHOT DIMENSIONS OF CALYX HOLE U18M

Depth	Northeast-Southwest Dimension[a]			Northwest-Southeast Dimension[a]			North-South Dimension[b]			East-West Dimension[b]		
	Preshot	Postshot	Difference	Preshot	Postshot	Difference	Preshot	Postshot	Difference	Preshot	Postshot	Difference
feet	inches	inches	inches	inches	inches	inches	inches	inches	inches	inches	inches	inches
12.5							36.972	36.968	-0.004	37.045	37.627	+0.582
12.8	36.70	36.38	-0.32	37.04	38.18	+1.14						
19.8	36.47	34.62	-1.85	36.39	36.10	-0.29						
20.0							36.811	point missing		36.501	point missing	
29.8	36.52	36.23	-0.29	36.46	37.96	+1.50						
30.0							36.997	37.955	+0.958	37.028	36.737	-0.291
39.8	36.38	35.89	-0.49	36.35	36.41	+0.06						
40.0							36.900	37.083	+0.183	36.891	36.553	-0.338
49.8	36.38	35.83	-0.55	36.28	36.61	+0.33						
50.0							36.578	point missing		36.643	36.244	-0.399
Average (at depths 20, 30, 40, 50)			-0.795			+0.40			+0.570			-0.343

[a] Measurements by hole caliper.
[b] Measurements between reference points set in walls.

TABLE 3.3 PRESHOT AND POSTSHOT DIMENSIONS OF CALYX HOLE U18N

Depth	Northeast-Southwest Dimension[a]			Northwest-Southeast Dimension[a]			North-South Dimension[b]			East-West Dimension[b]		
	Preshot	Postshot	Difference	Preshot	Postshot	Difference	Preshot	Postshot	Difference	Preshot	Postshot	Difference
feet	inches	inches	inches	inches	inches	inches	inches	inches	inches	inches	inches	inches
5.0							37.232	37.250	+0.018	37.644	37.665	+0.021
5.5	37.32	36.33	-0.99	36.43	36.89	+0.45						
10.0							37.107	37.229	+0.122	36.884	36.520	-0.364
10.5	36.55	36.18	-0.37	36.41	36.25	-0.16						
20.0							37.049	37.061	+0.012	36.763	36.766	+0.003
20.5	36.47	36.34	-0.13	36.29	36.47	+0.18						
30.0							36.844	36.860	+0.016	36.626	36.643	+0.017
30.5	36.42	36.33	-0.09	36.23	36.40	+0.17						
40.0							36.858	36.864	+0.006	36.609	36.604	-0.005
40.5	36.50	36.42	-0.08	36.32	36.34	+0.02						
50.0							36.814	36.894	+0.080	36.759	36.716	-0.043
50.5	36.39	36.32	-0.07	36.23	36.33	+0.10						
60.0							36.607	36.642	+0.035	36.600	36.566	-0.034
60.5	36.40	36.28	-0.12	36.20	36.45	+0.25						
Average (at depths 20, 30, 40, 50, 60)			-0.098			+0.144			+0.029			-0.012

[a] Measurements by hole caliper.
[b] Measurements between reference points set in walls.

TABLE 3.4 PRESHOT AND POSTSHOT DIMENSIONS OF CALYX HOLE U180

Depth	East-West Dimension[a]			North-South Dimension[a]			North-South Dimension[b]			East-West Dimension[b]		
	Preshot	Postshot	Difference	Preshot	Postshot	Difference	Preshot	Postshot	Difference	Preshot	Postshot	Difference
feet	inches	inches	inches	inches	inches	inches	inches	inches	inches	inches	inches	inches
9.8 10.0	36.35	36.29	-0.06	36.33	36.27	-0.06	36.804	36.804	0.000	36.904	36.890	-0.014
19.8 20.0	36.41	36.39	-0.02	36.40	36.33	-0.07	37.160	37.153	-0.007	36.989	36.973	-0.016
29.8 30.0	36.46	36.37	-0.09	36.41	36.33	-0.08	37.076	37.076	0.000	36.847	36.846	-0.001
39.8 40.0	36.40	36.27	-0.13	36.31	36.25	-0.06	36.701	36.698	-0.003	36.861	36.832	-0.029
49.8 50.0	36.44	36.28	-0.16	36.36	36.43	+0.07	36.714	36.716	+0.002	36.804	36.673	-0.131
59.8 60.0	36.52	36.38	-0.14	36.46	36.38	-0.08	36.816	36.804	-0.012	36.766	36.681	-0.085
Average (at depths 20, 30, 40, 50, 60)			-0.11			-0.04			-0.004			-0.052

[a] Measurement by hole caliper.
[b] Measurements between reference points set in walls.

TABLE 3.5 PRESHOT AND POSTSHOT DIMENSIONS OF CALYX HOLE U18P

Depth	North-South Dimension[a]			East-West Dimension[a]			North-South Dimension[b]			East-West Dimension[b]		
	Preshot	Postshot	Difference	Preshot	Postshot	Difference	Preshot	Postshot	Difference	Preshot	Postshot	Difference
feet	inches	inches	inches	inches	inches	inches	inches	inches	inches	inches	inches	inches
10.0							37.357	37.371	+0.014	36.698	36.652	-0.046
10.4	37.22	36.91	-0.31	36.42	36.22	-0.20						
20.0							36.766	36.767	+0.001	36.794	36.797	+0.003
20.4	36.47	36.32	-0.15	36.42	36.28	-0.14						
30.0							36.548	36.542	-0.006	36.617	36.616	-0.001
30.4	36.38	36.27	-0.11	36.34	36.18	-0.16						
40.0							36.665	36.666	+0.001	36.728	36.727	-0.001
40.4	36.41	36.28	-0.13	36.43	36.34	-0.09						
49.4	36.35	36.18	-0.17	37.43	37.34	-0.09						
50.0							36.437	36.431	-0.006	37.233	37.236	+0.003
60.0							36.557	36.603	+0.046	36.761	36.700	-0.061
60.4	36.35	36.33	-0.02	36.30	36.12	-0.18						
Average (at depths 20, 30, 40, 50, 60)			-0.12			-0.13			+0.007			-0.011

a Measurements by hole caliper.
b Measurements between reference points set in walls.

TABLE 3.6 ZONES OF ANOMALOUS MAGNETISM IN NX CORE BORINGS

Preshot		Postshot	
NCG Core Boring Number	Depth	NCG Core Boring Number	Depth
	feet		feet
26	2.0-14.0	46	None
30	53.5-56.0	47	79.0-85.0 (Inclined)
	71.0-74.0	48	43.0-45.0
35	None		49.0-52.0
36	40.0 (Questionable)		57.0-58.0
	61.0-62.0	49	8.0
37	None		58.0-59.5
38	75.0-76.0	50	None
39	None		
40	None		
41	44.0-46.0		
42A	None		
43	None		
44	87.0-89.0 (Inclined)		
45	20.0 (Inclined)		
	77.0-80.0 (Inclined)		

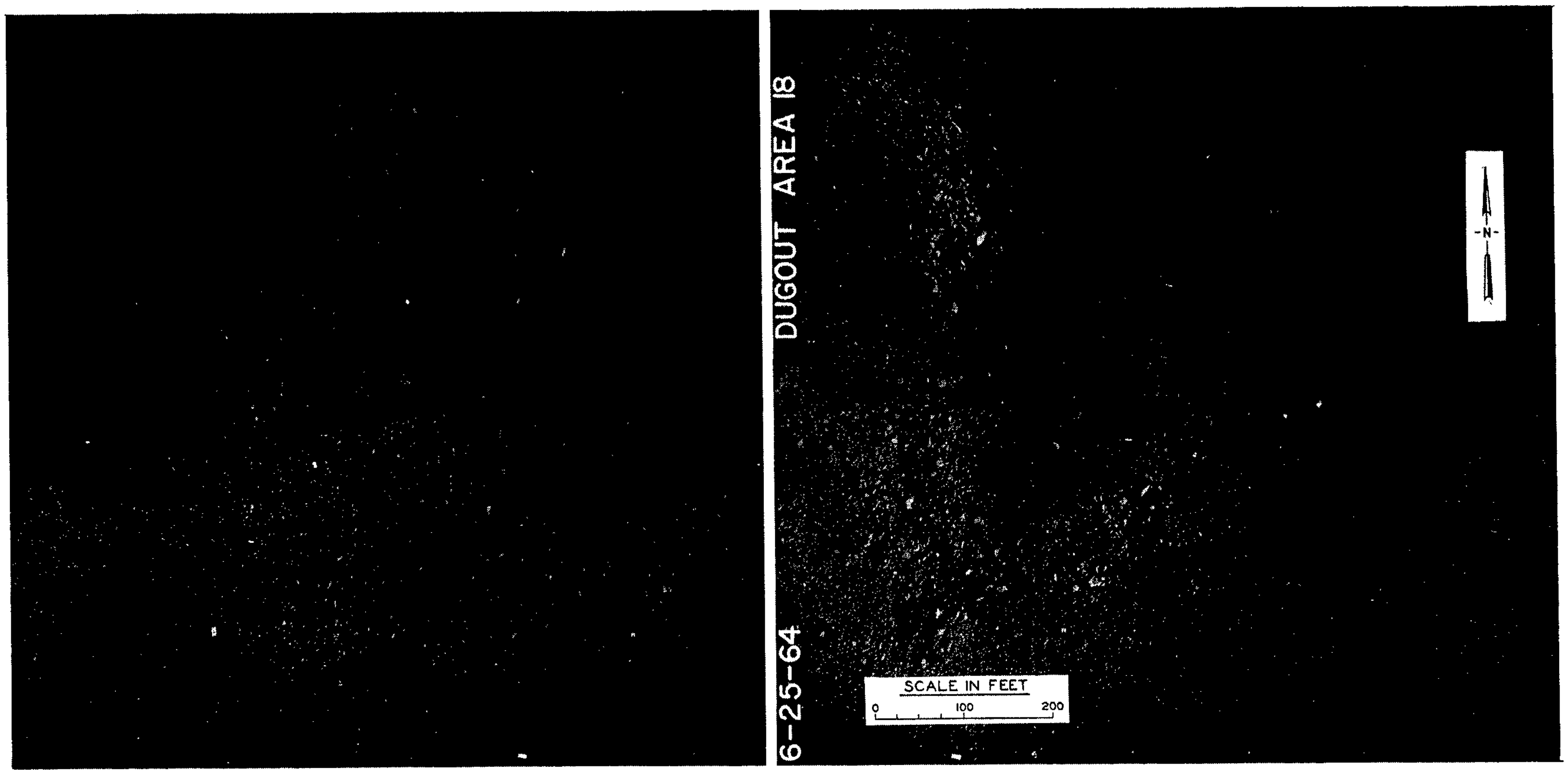


Figure 3.1 Vertical aerial view of Dugout crater, with photos paired for stereoscopic viewing.

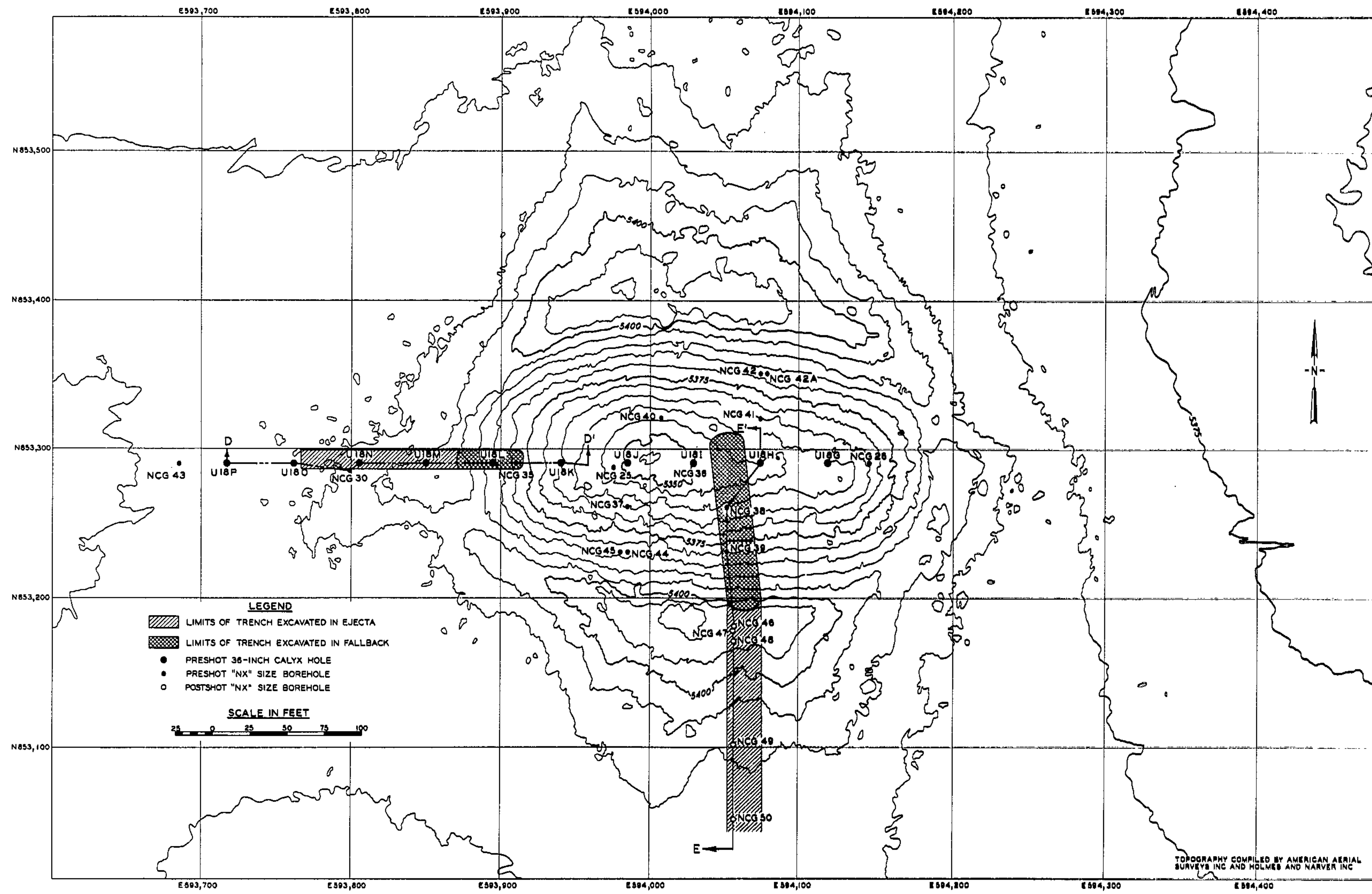


Figure 3.2 Postshot topography and locations of trenches and borings.

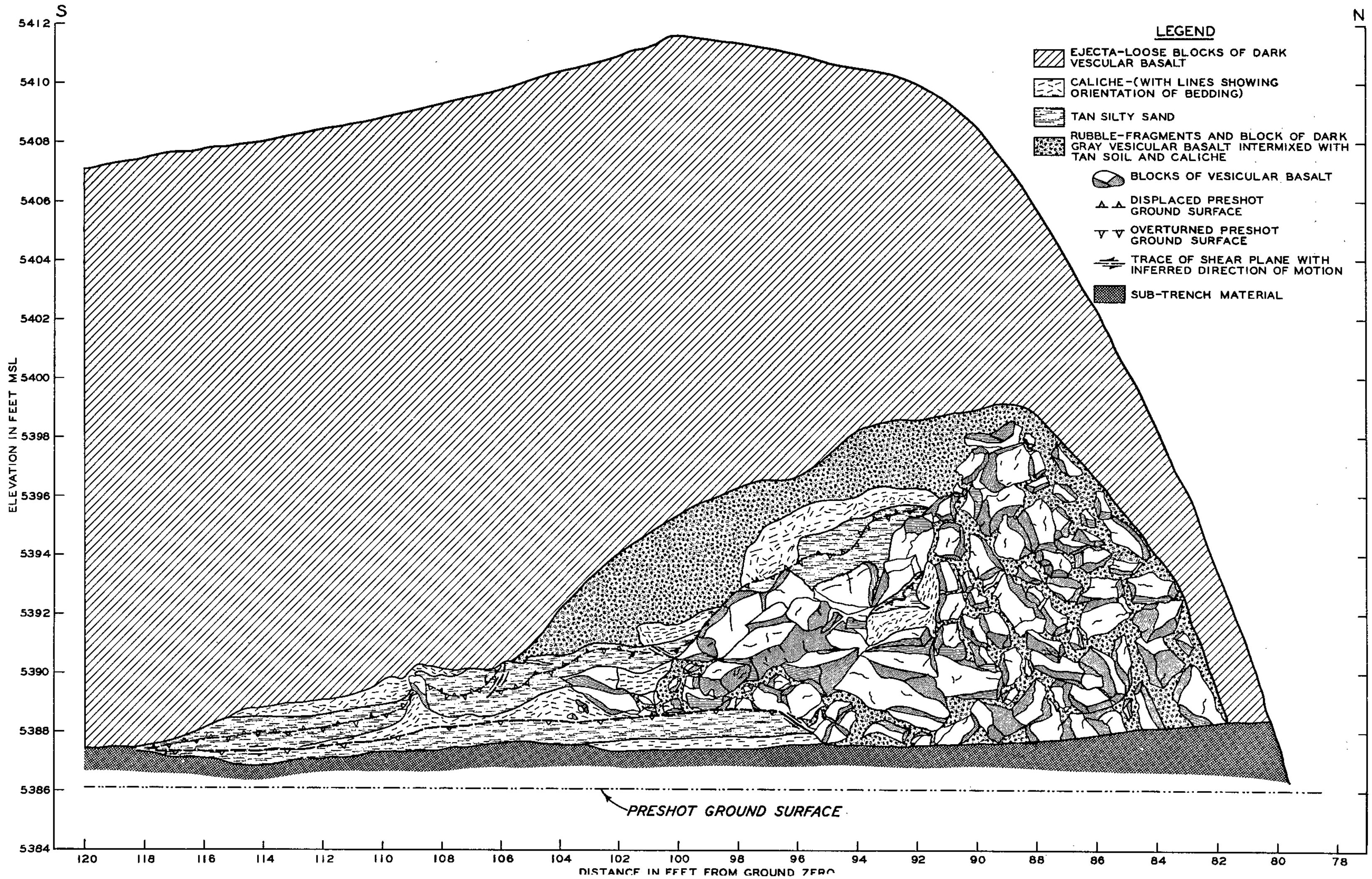


Figure 3.3 West wall of trench bearing south from side of crater. Trench was later extended into crater.

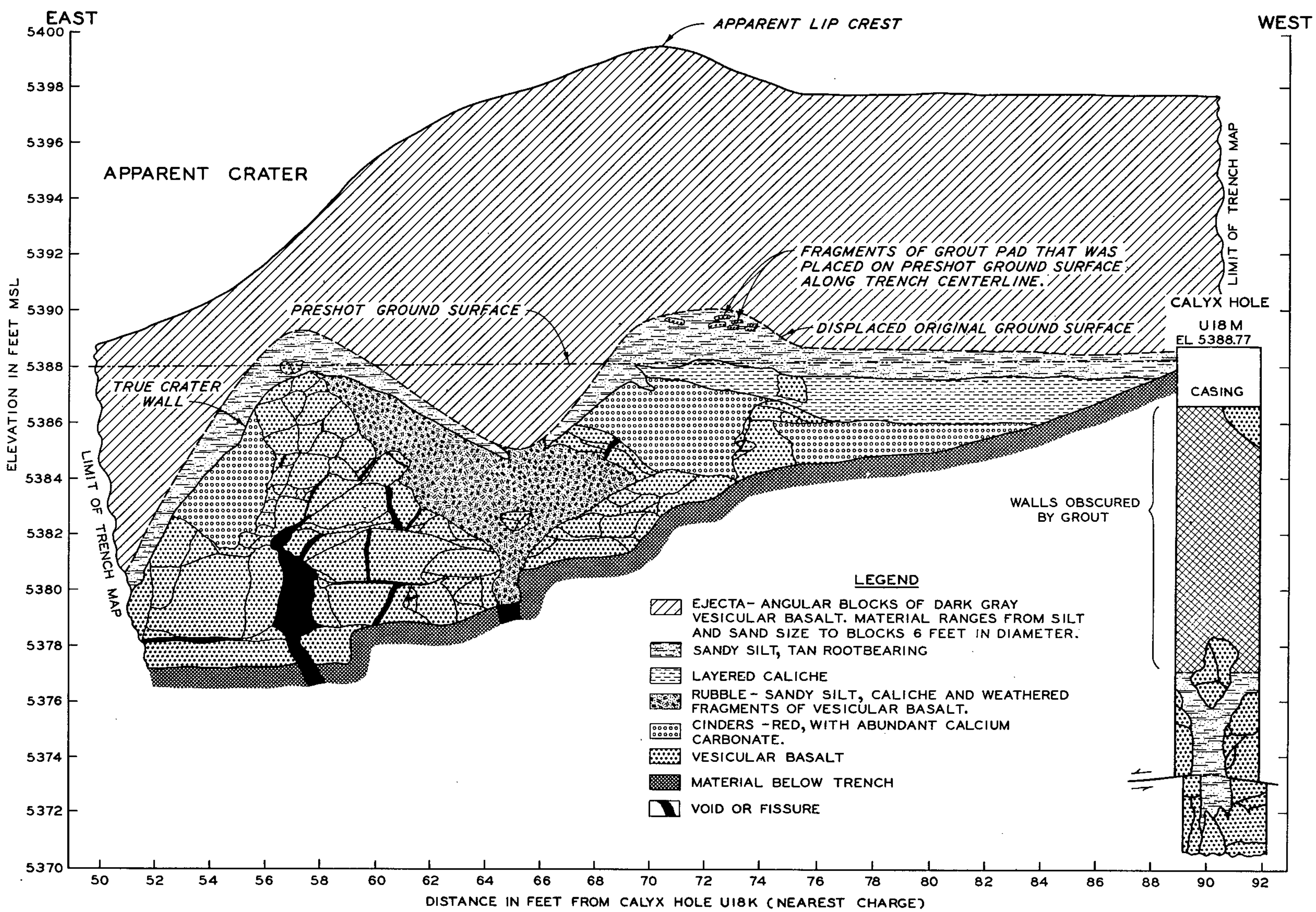
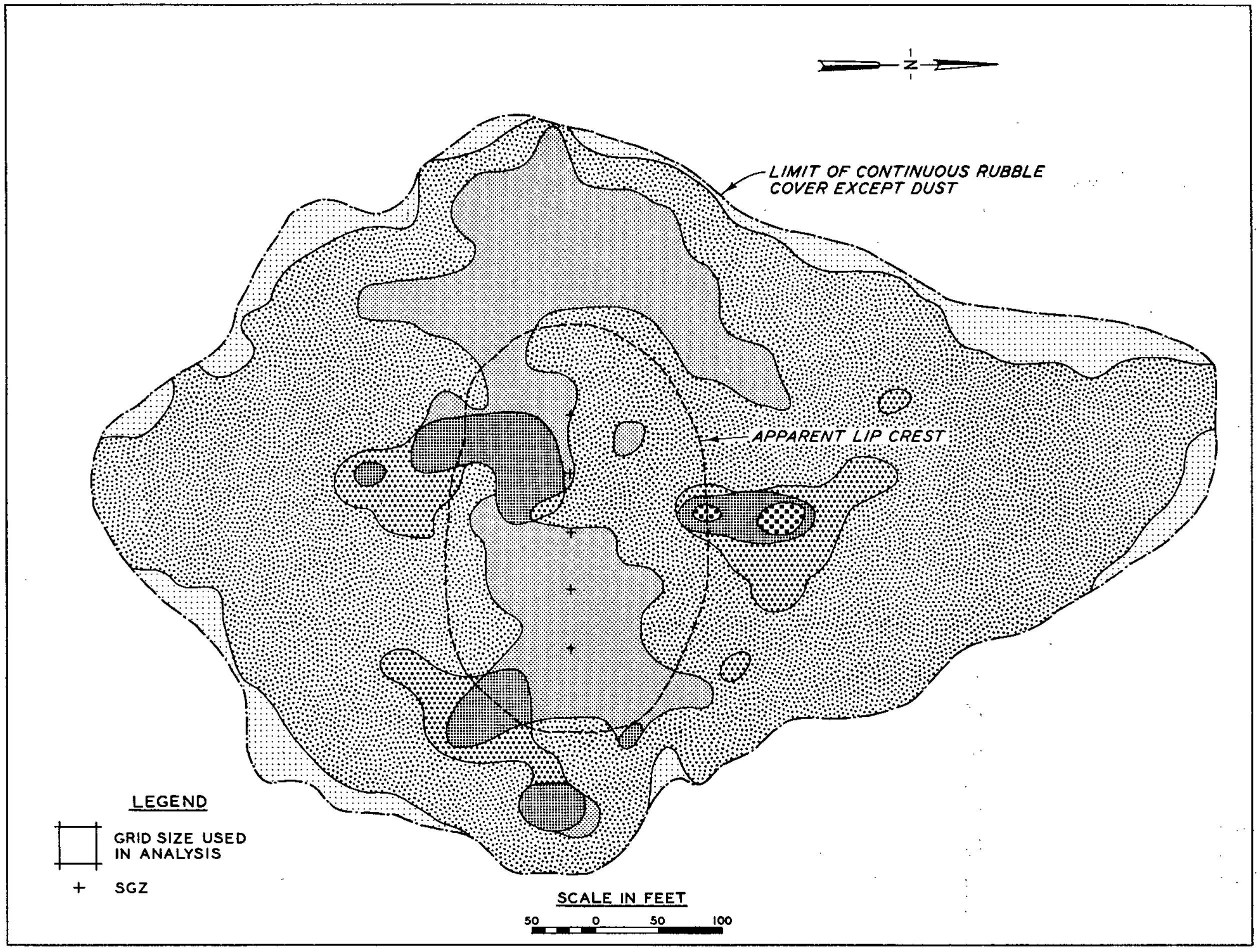
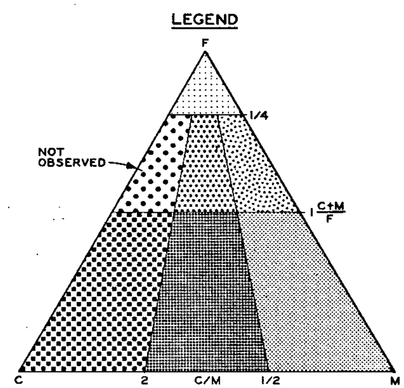


Figure 3.4 South wall of trench bearing west from end of crater.





NOTE:

GRAIN SIZE OF EJECTA AND FALLBACK WITHIN EACH GRID SQUARE WAS ANALYZED IN TERMS OF THE RELATIVE PROPORTION OF ITS 3 MAIN COMPONENTS: C OR FRAGMENTS > 2 FEET IN DIAMETER; M OR FRAGMENTS BETWEEN 3 INCHES AND 2 FEET IN DIAMETER; AND F OR FRAGMENTS < 3 INCHES IN DIAMETER.

COMPOSITION TRIANGLE CMF WAS SUBDIVIDED INTO 7 CONVENIENT SIZE CLASSES USING SELECTED C/M AND C + M/F RATIO LINES.

THE GEOGRAPHIC DISTRIBUTION OF PERTINENT SIZE CLASSES ARE SHOWN ON THE ACCOMPANYING MAP.

Figure 3.5 Aerial distribution of selected ejecta-fallback size class.

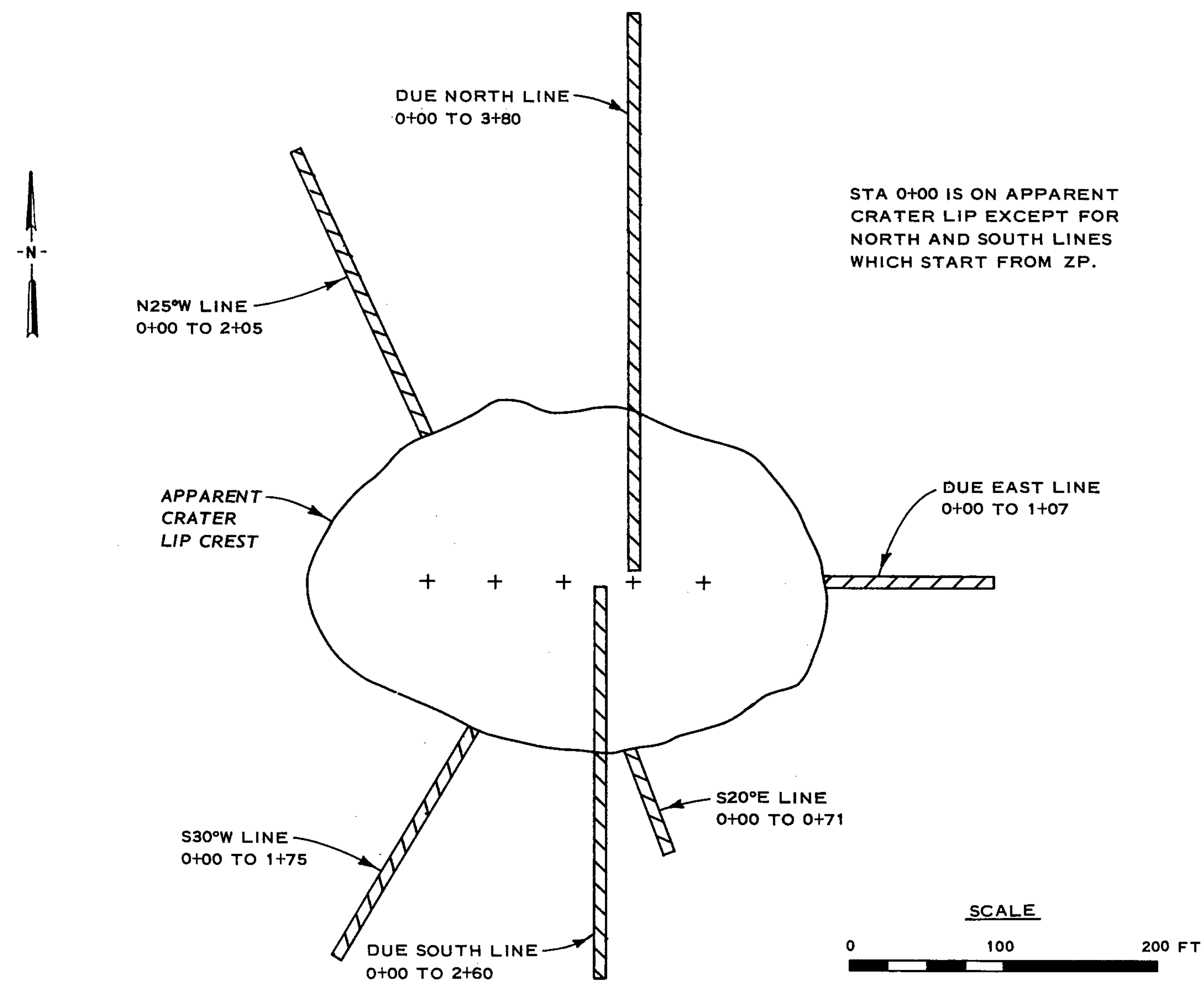


Figure 3.6 Location of photo-grid traverses through and adjacent to crater.

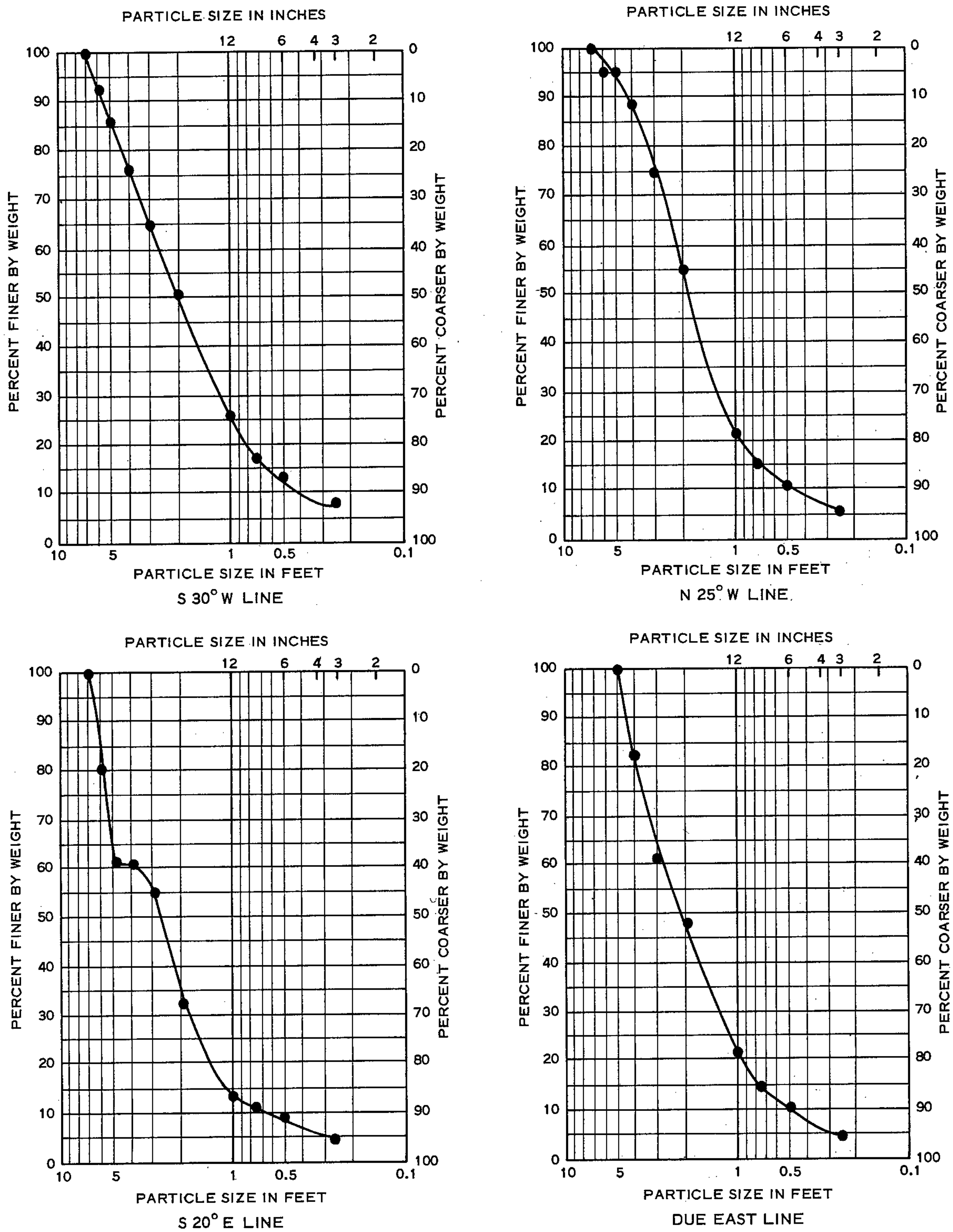


Figure 3.7 Cumulative frequency curves of ejecta grain size along selected photo-grid traverse lines.

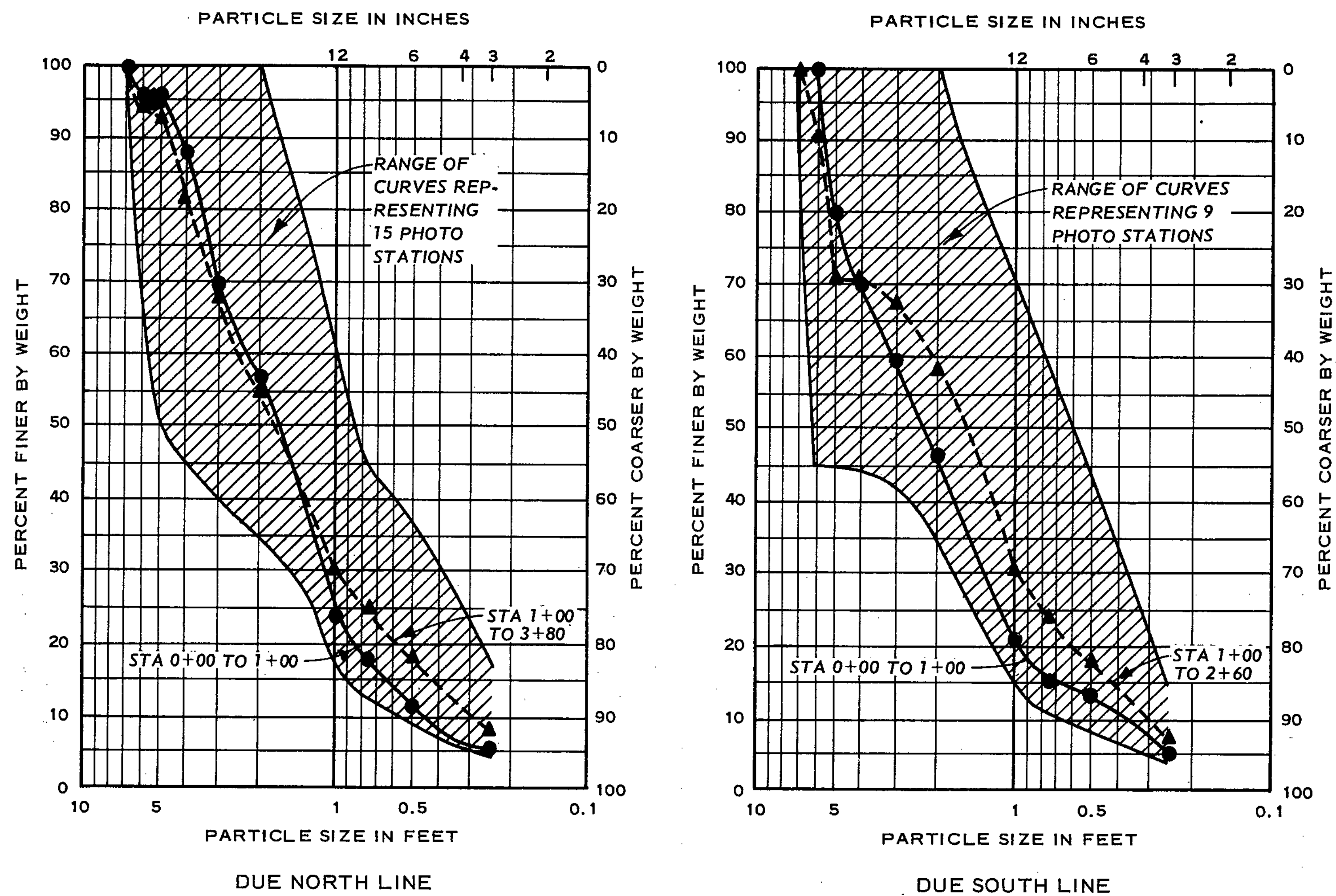


Figure 3.8 Cumulative frequency curves of ejecta and fallback grain size along selected photo-grid traverse lines.

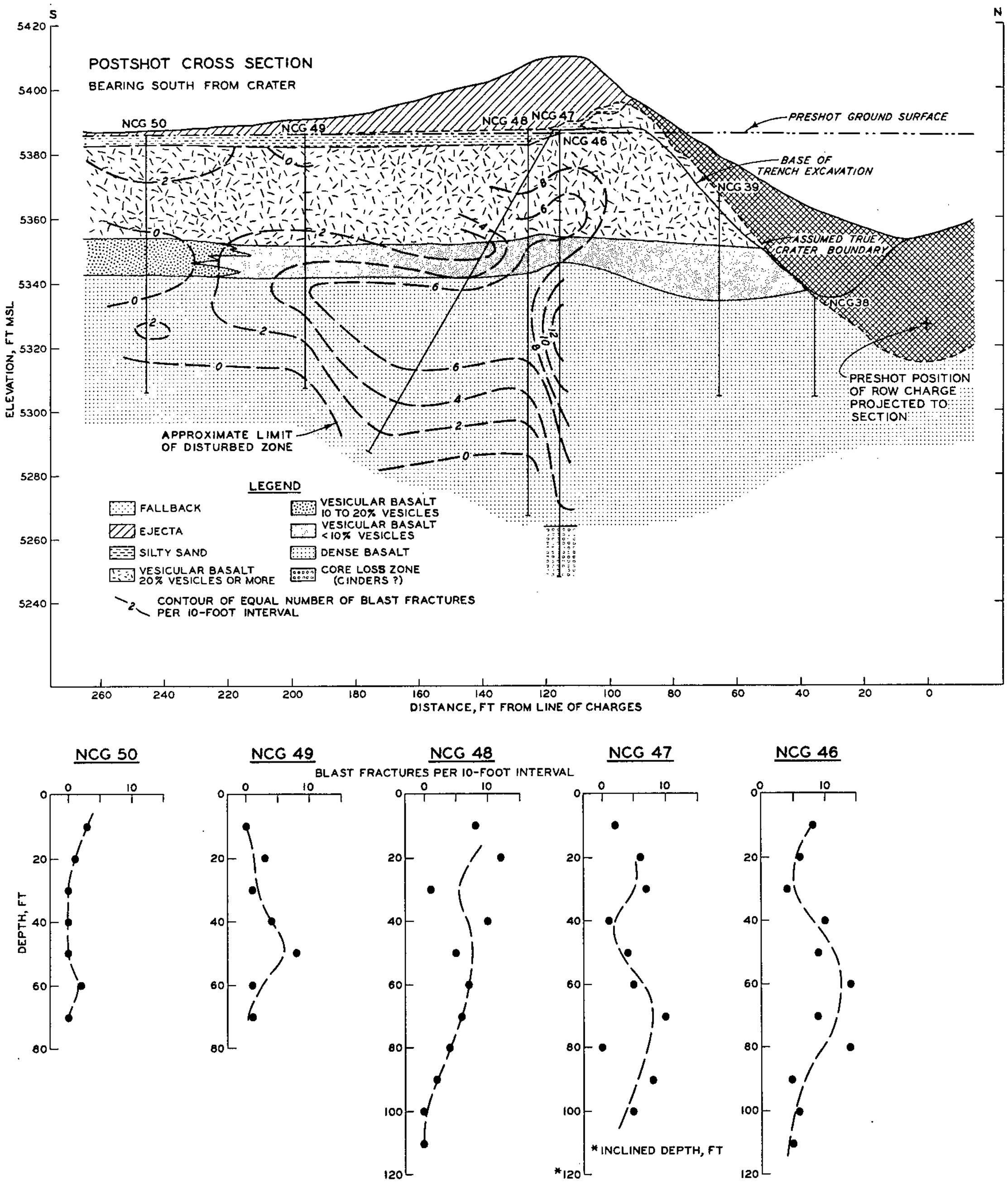


Figure 3.9 Blast fractures in postshot borings, south section (E-E').

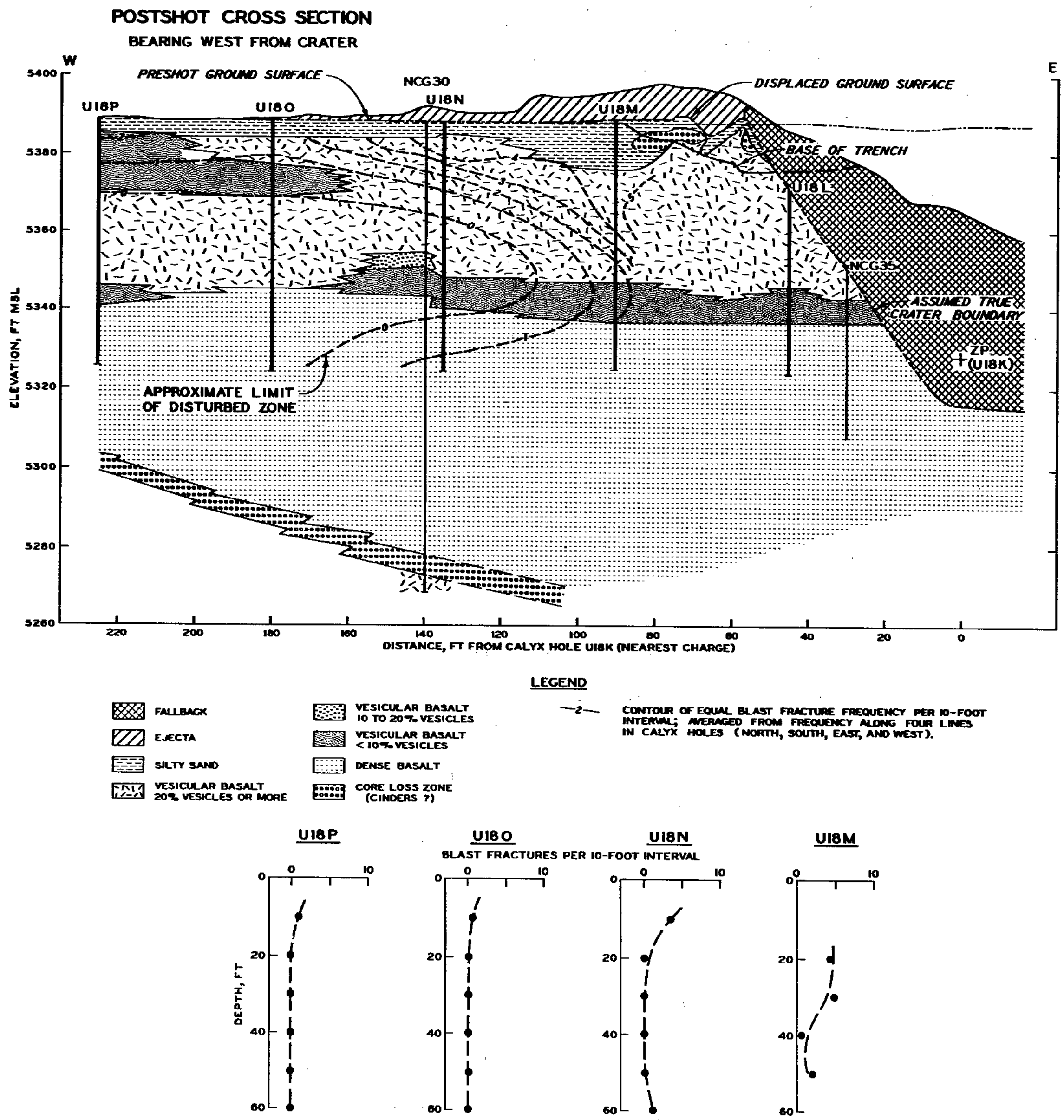


Figure 3.10 Blast fractures in surviving calyx holes, west section (D-D').

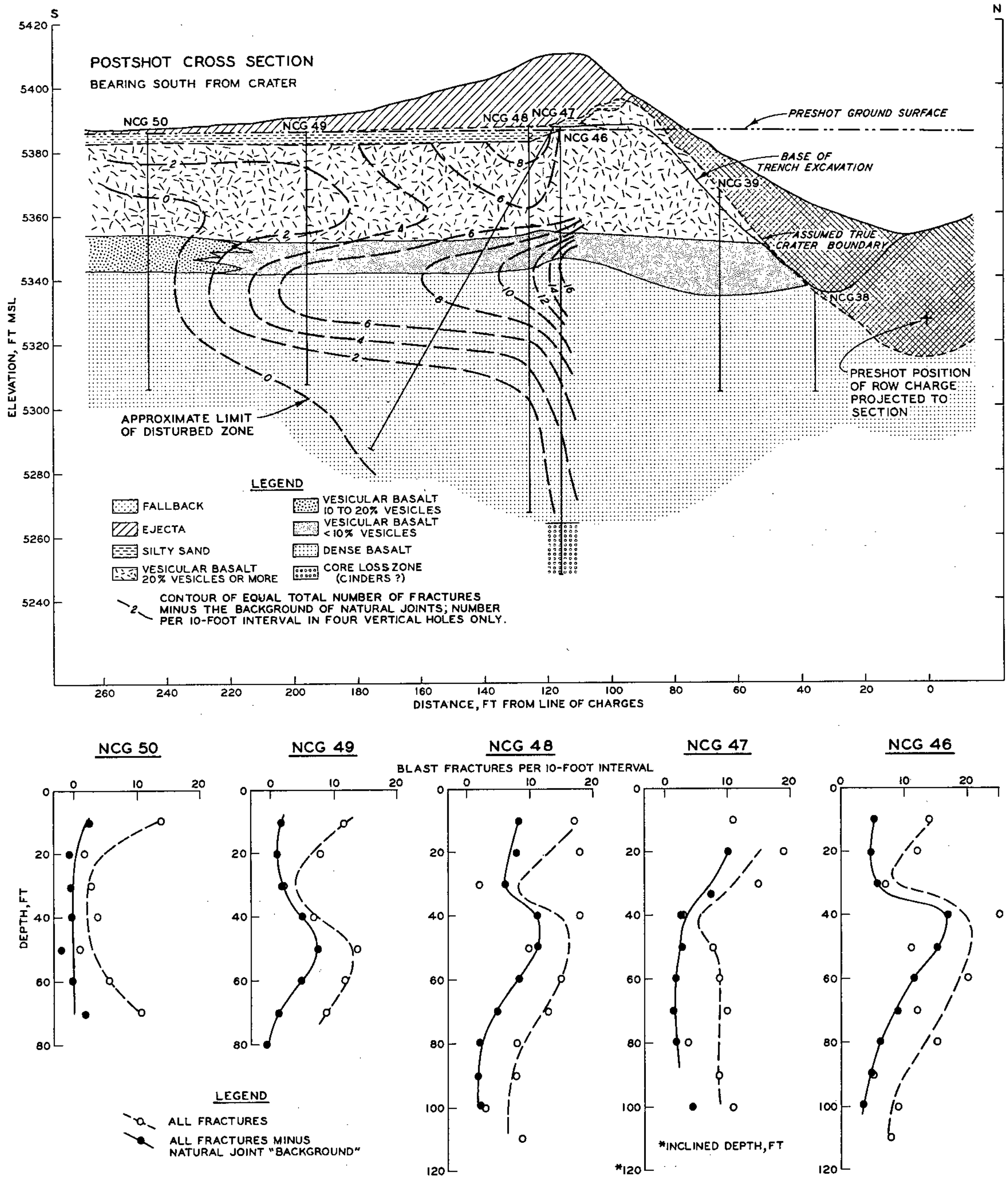


Figure 3.11 Increased fracturing evident in postshot borings, south section (E-E').

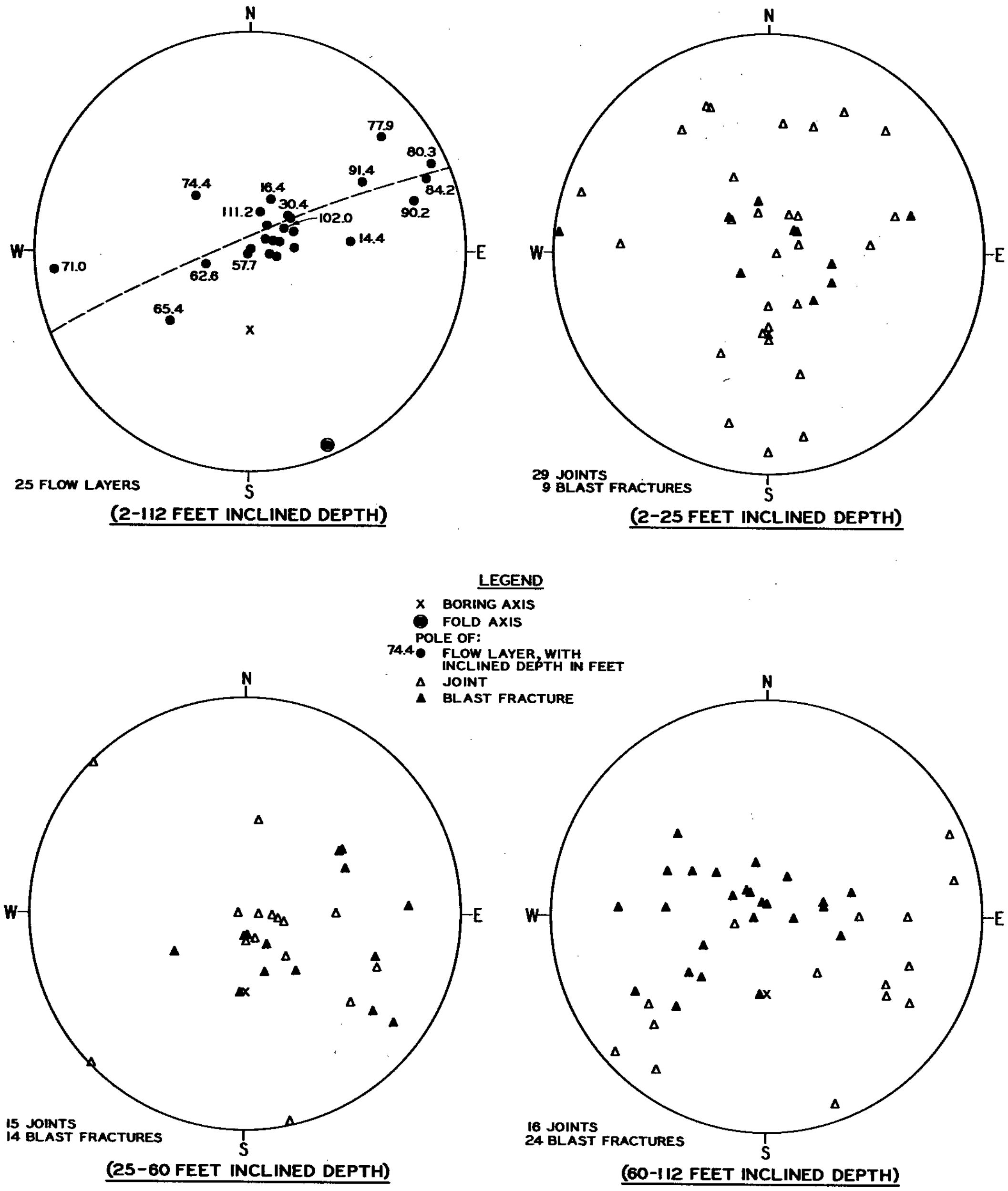


Figure 3.12 Orientations of flow structures, joints, and blast fractures in inclined Boring NCG 47.

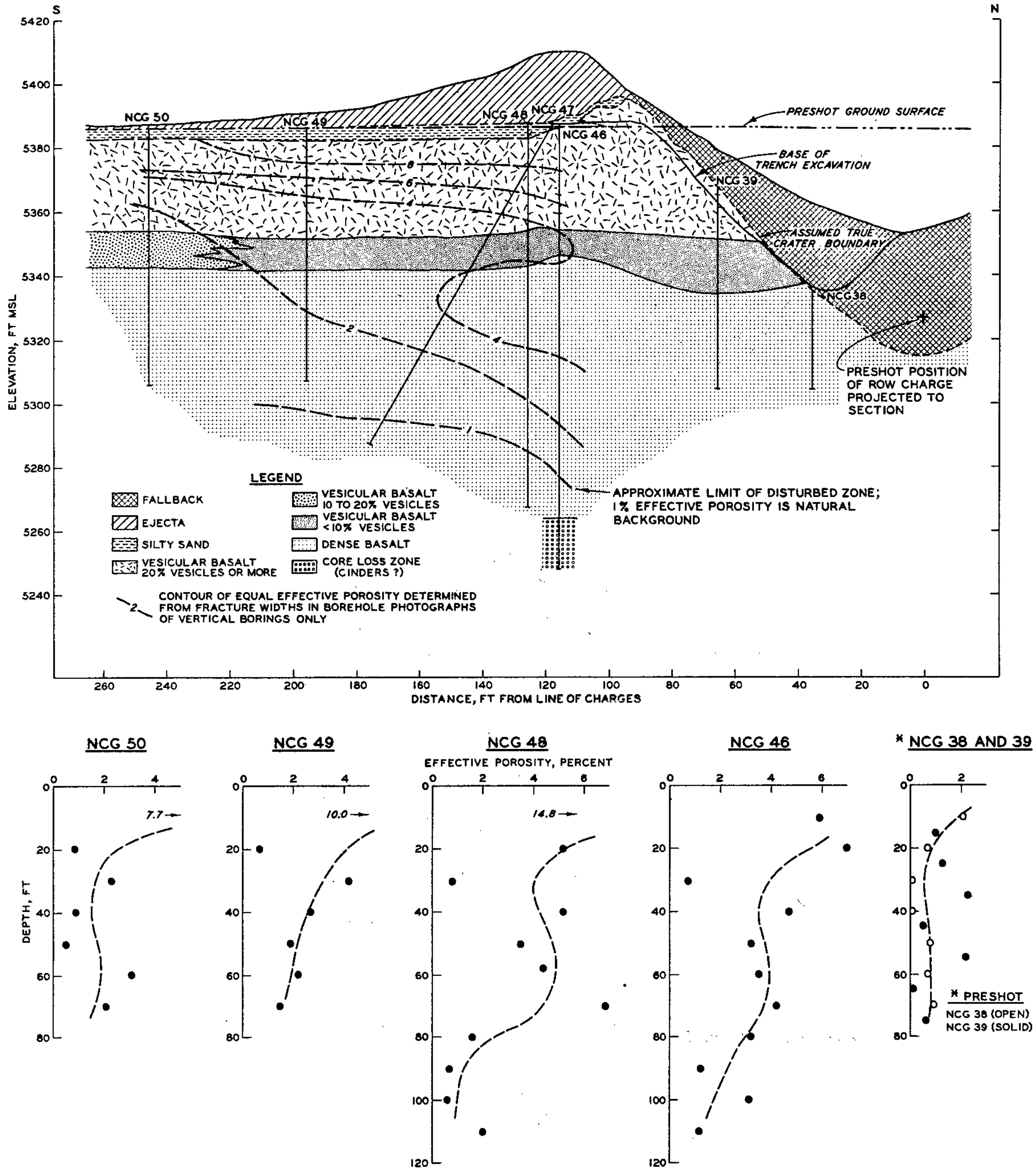


Figure 3.13 Effective porosity in postshot borings, south section (E-E').

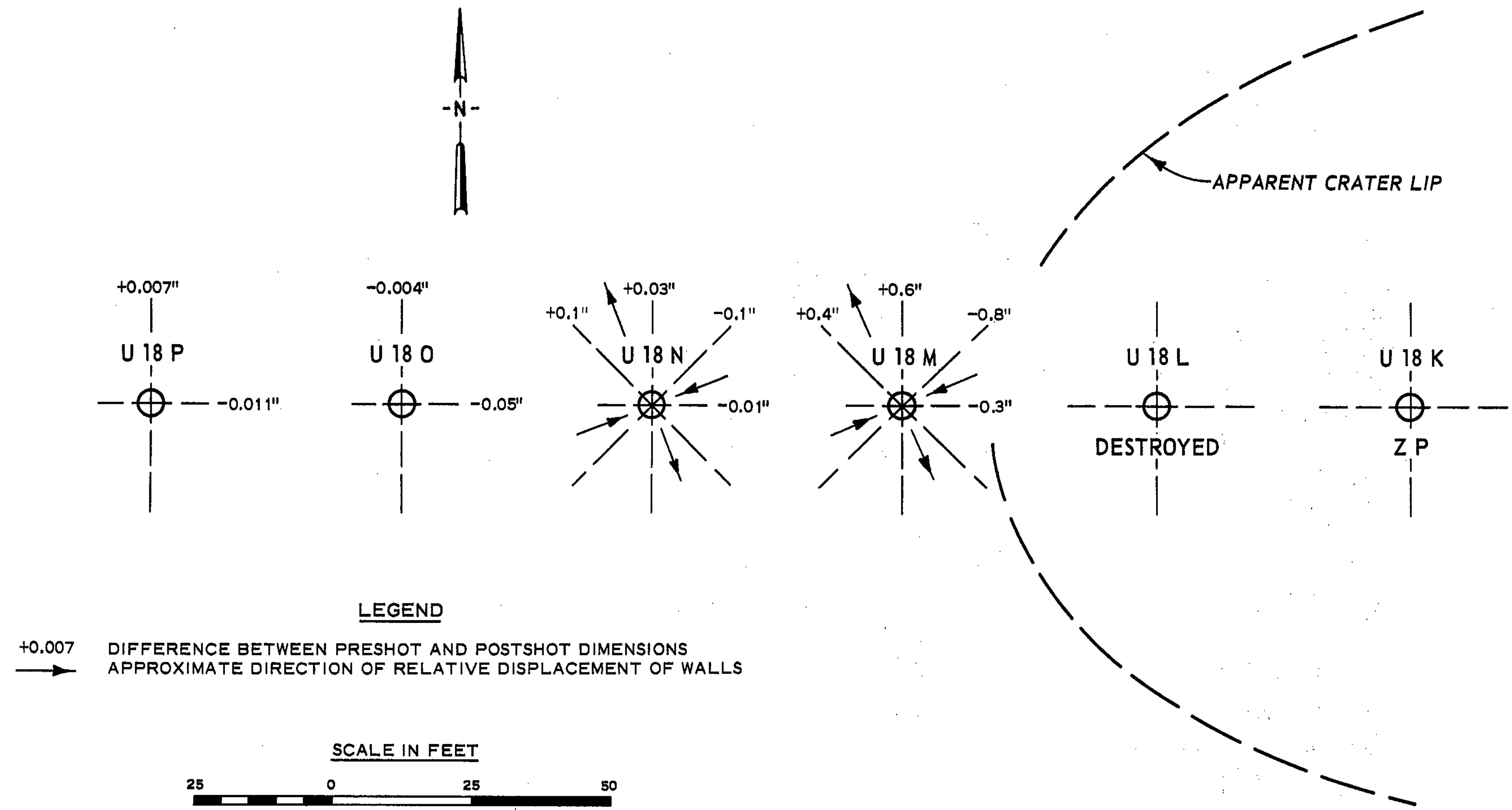


Figure 3.14 Deformation in sheared zone as indicated by changes in dimensions of sand-filled calyx holes.

CHAPTER 4

DISCUSSION OF SUBSURFACE DISPLACEMENTS IN RUPTURE ZONE

Investigations of the surviving calyx holes and the trench at the west end of the crater indicate that a portion of the rupture zone materials has been displaced toward the crater with respect to materials lying immediately below. These displacements are believed to have occurred during the formation of the crater. A description of these displacements together with similar displacements observed at other craters is presented below.

4.1 GROSS FEATURES OF DISPLACED ZONE

On the basis of the offsets in calyx hole U18M (Appendix B) and in the trench at the true lip (Figure 3.4), it is known that the entire upper portion of the mass at the west end is offset toward the crater with respect to that below. The offsets along individual flat joints increase upward from about 1/2 inch on the flat joint that cuts the hole at 44 feet in depth, thus indicating that the mass involved was at least that thick at U18M. It should be emphasized that the conspicuous shearing has taken place along several flat joints distributed throughout rather than a single zone at its base. An opening of fissures along steep joints accompanied this lateral shift. Two of these are evident in the trench.

Strictly speaking, the craterward offset is only relative to material below, and the net movement of some mass points is undoubtedly away from the crater.

Since no craterward relative displacement is evident in calyx hole U18N, the outer edge of the zone of craterward spreading is apparently bracketed at a distance between 35 and 78 feet from the edge of the true crater. The front side of the mass corresponds to the true crater wall.

4.2 EVIDENCE OF DISPLACEMENTS TOWARD THE CRATER AT OTHER EXPERIMENTS

Relative or actual displacements toward the crater have taken place at several other cratering experiments.

Columns of soil emplaced in a faintly bedded alluvial clay were offset (Figure 4.1) by small explosions (27 pounds of C-4 high explosive) in a test program described in Reference 26. Much of the offset has apparently taken place along horizontal planes which parallel stratification. The craterward offset (at depths of 0 to 3 feet) is mostly relative to material below, and usually materials above and below have net displacements away from the crater. Other craters of the same series show the same phenomena.

Several craters of the Air Vent series (Reference 27) in moist playa silt exhibit displacements toward the crater, and one of these is illustrated in Figure 4.2. Significant displacement of

metal tabs embedded in sand columns is indicated by the arrows in the figure. A portion of the silt outside the true crater wall has moved upward and toward the crater from its preshot position. Similar movement was observed during the Pre-Buggy series in desert alluvium (Reference 28 and Figure 4.3).

In Operation Snowball (Reference 29) a crater formed by detonation of a 500-ton surface charge of TNT exhibited evidence of displacement toward the crater (Figure 4.4). The strata are wet clay, silt, and gravel. Arcuate topographic depressions (Figure 4.5) formed at a distance beyond the crater indicate approximate limits of these displaced masses. The high water table at this site may have accentuated the phenomenon.

During 1-pound high-explosive detonations in a carefully controlled sand medium, slumping was observed (Figure 4.6) with the slumped materials coming to rest in the lower portion of the fallback or the close-in portion of the rupture zone (Reference 30).

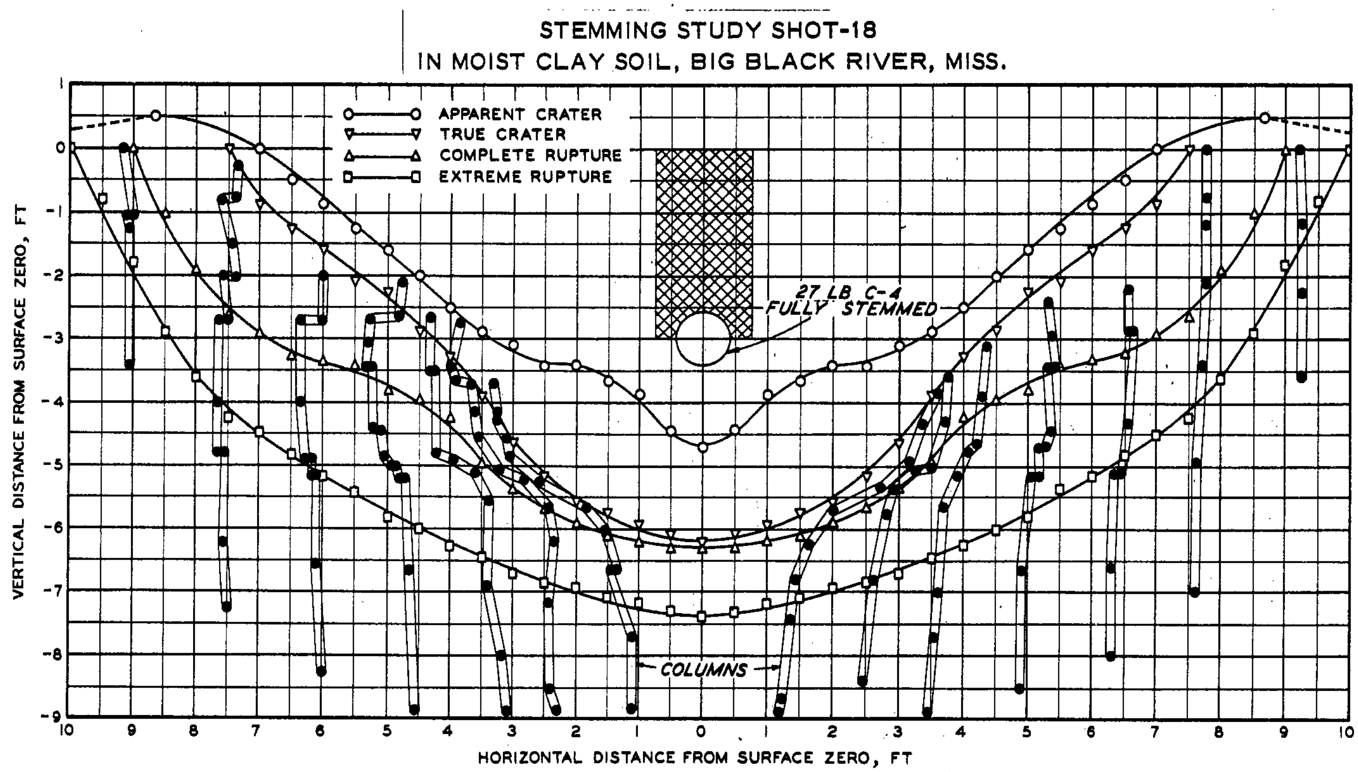


Figure 4.1 Cross section of crater in alluvial clay showing relative craterward offset of vertical soil columns (adapted from Reference 26).

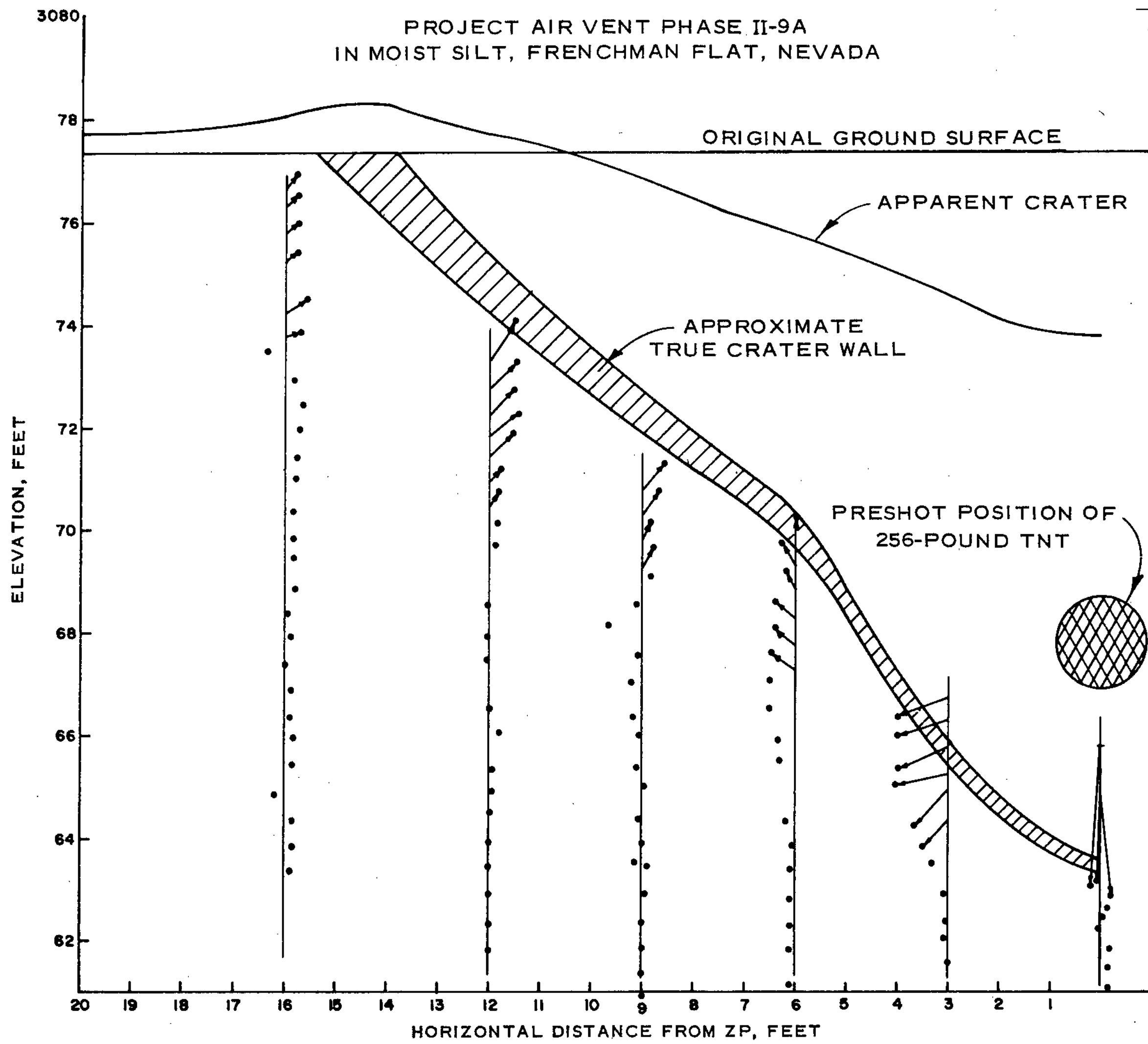
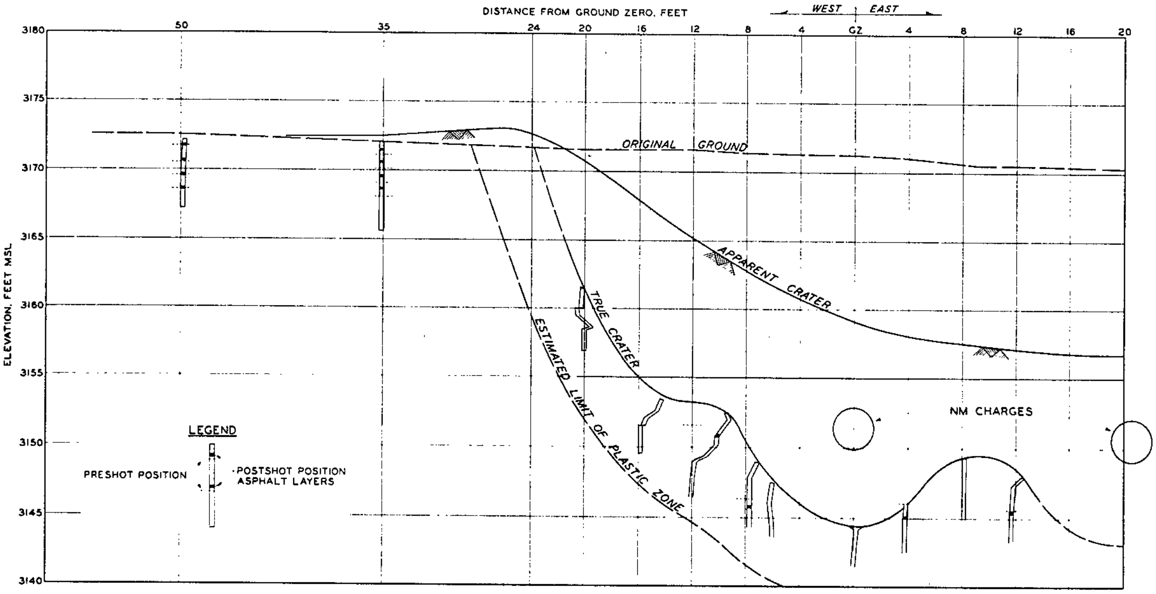
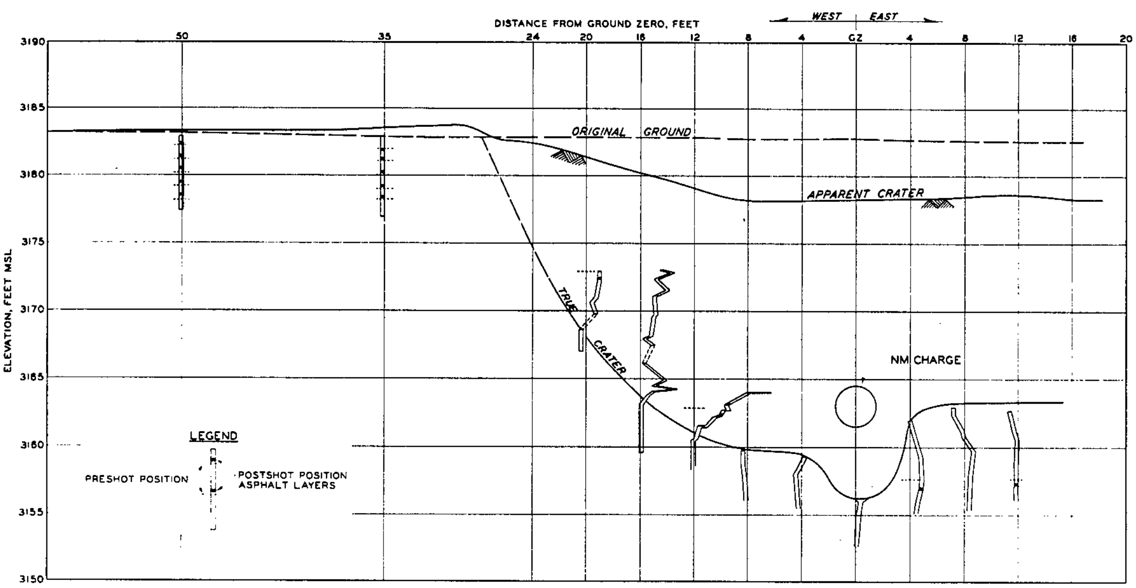


Figure 4.2 Cross section of crater in playa silt showing relative craterward displacement of marker tabs (adapted from Reference 27).



(a) POSTSHOT SAND COLUMN POSITIONS, LONGITUDINAL RADIAL, FIVE 1000-LB NITROMETHANE CHARGES BURIED AT A DEPTH OF 19.8 FEET AND SPACED 20.6 FEET APART.



(b) POSTSHOT SAND COLUMN POSITIONS, LONGITUDINAL RADIAL, FIVE 1000-LB NITROMETHANE CHARGES BURIED AT A DEPTH OF 19.8 FEET AND SPACED 25.8 FEET APART.

Figure 4.3 Sand column displacement from two of the Project Pre-Buggy row craters (from Reference 28).

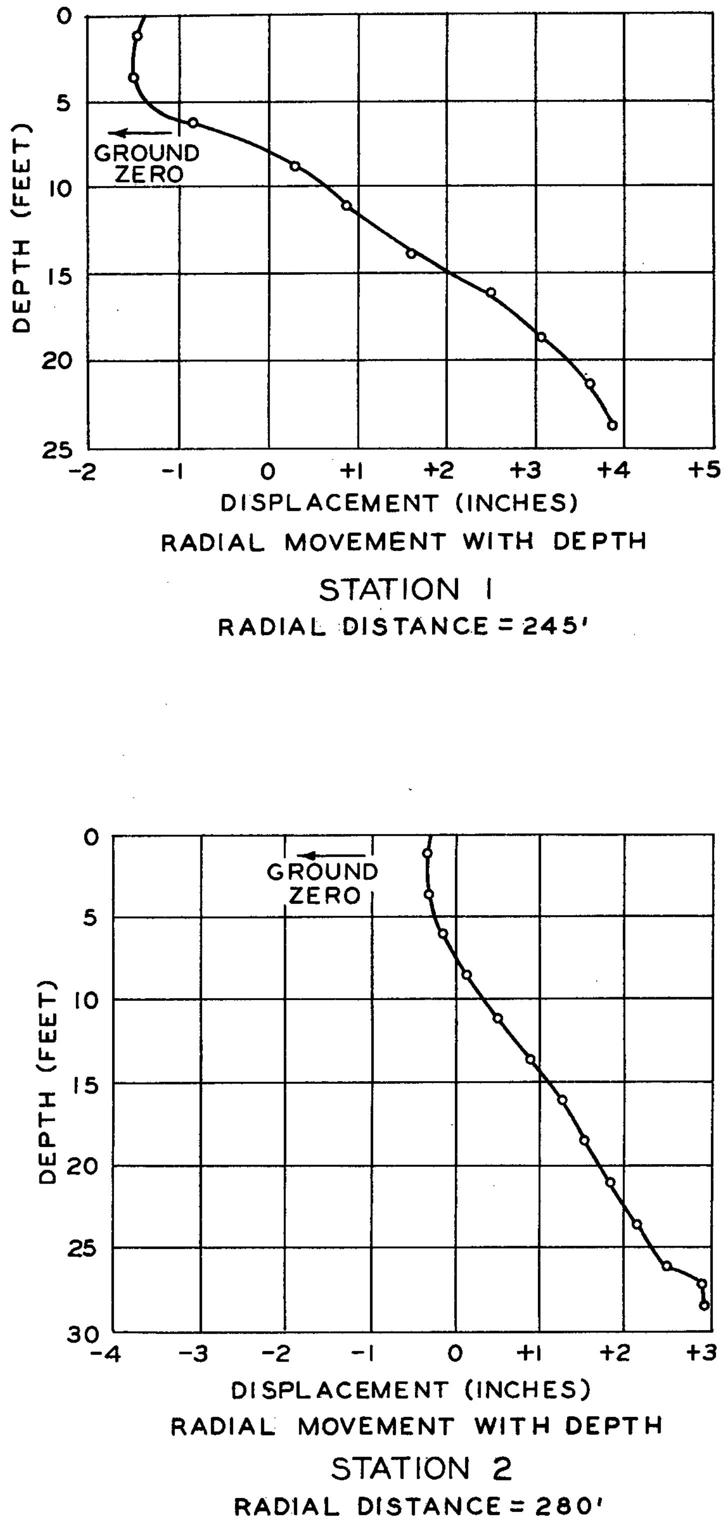


Figure 4.4 Measured permanent horizontal displacements, Project Snowball (from Reference 29).

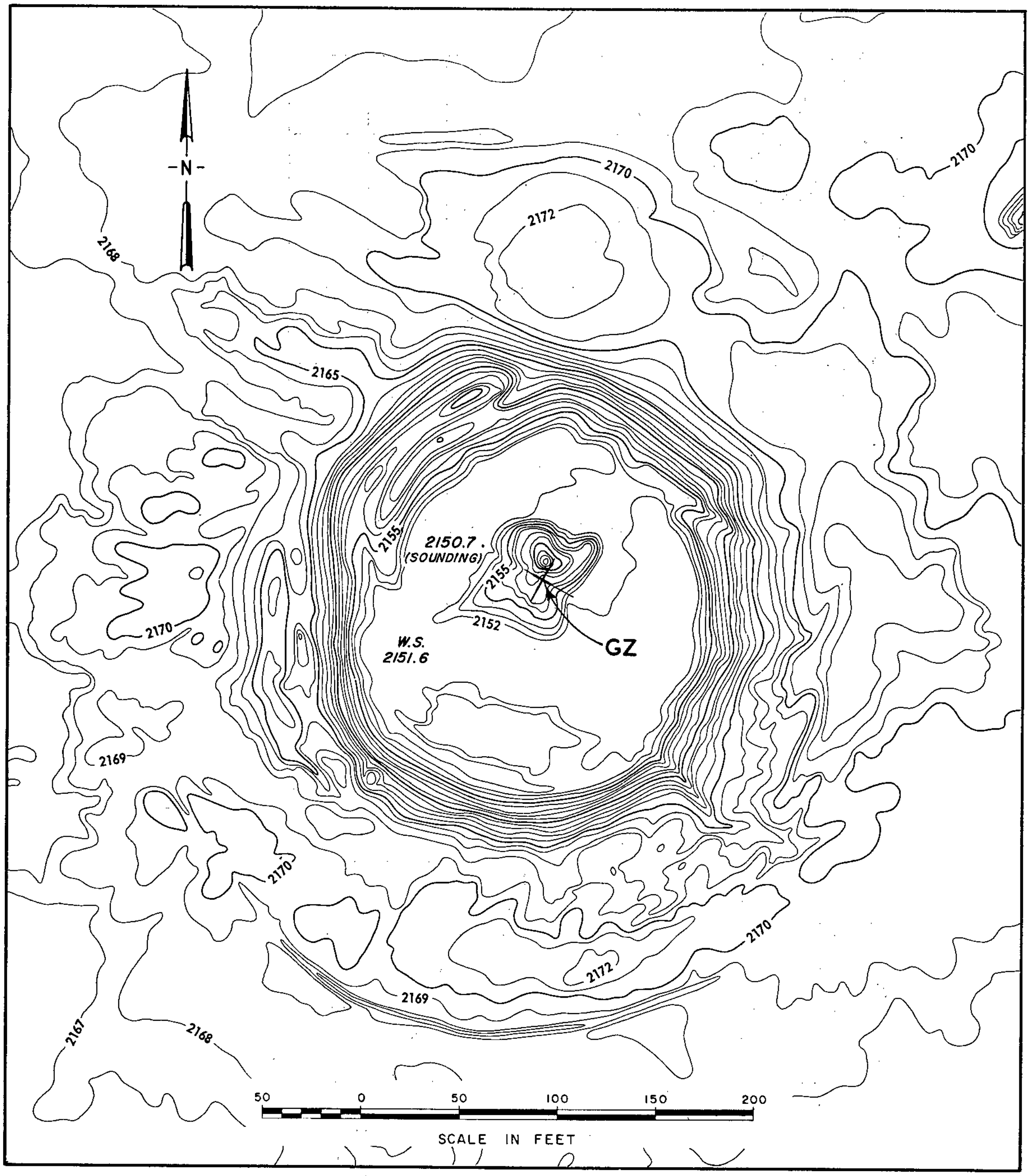


Figure 4.5 Postshot topography of Operation Snowball crater showing arcuate depressions beyond the west rim.

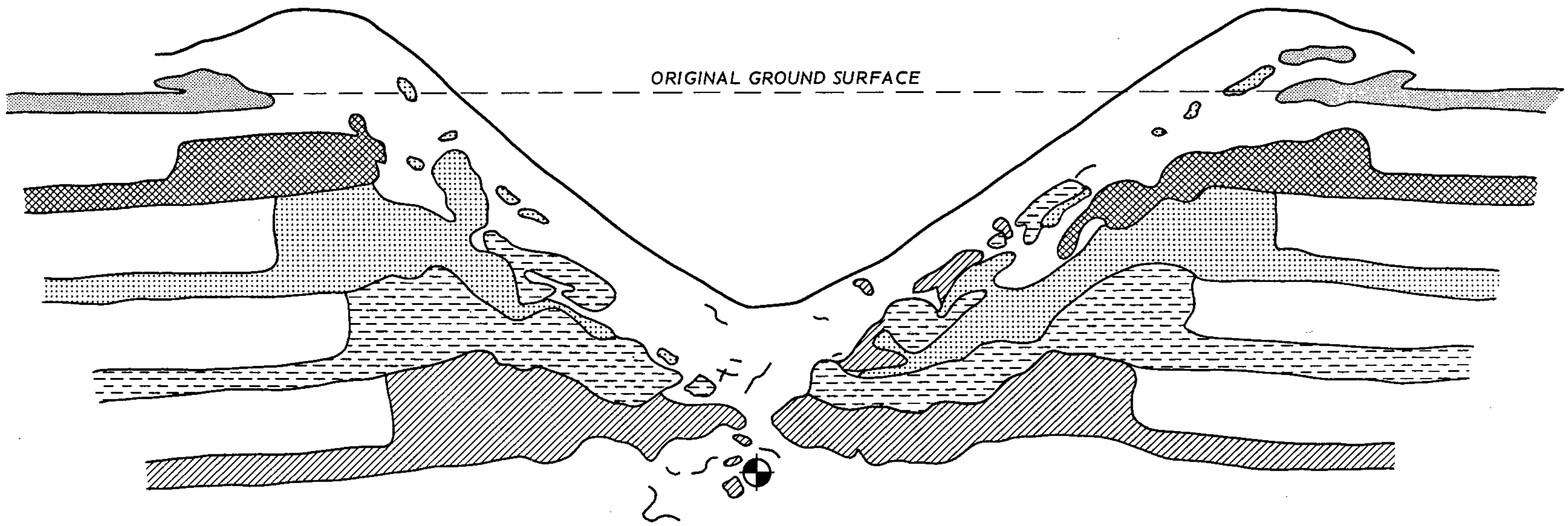


Figure 4.6 Postshot configuration of colored sand layers produced by one pound of C-4 at optimum depth (from Reference 30).

CHAPTER 5

SUMMARY AND CONCLUSIONS

The Dugout cratering experiment was conducted on Buckboard Mesa at the NTS, Nye County, Nevada. It consisted of the simultaneous detonation of five 20-ton nitromethane charges in linear array at a depth of 59 feet in dry basalt. The engineering and geological investigations utilized the following sources of data: preshot and postshot aerial photographs and topographic maps, NX core from 15 preshot and 5 postshot borings, 10 preshot calyx holes, 4 of the same calyx holes that survived the blast, 2 postshot trenches, borehole photographs from most of the borings, physical tests on selected core samples, bulk density determination of a large ejecta sample, field vibroseismic measurements, and closeup grid photographs of the ejecta.

Buckboard Mesa is capped by a complex basalt sheet about 100 to 200 feet thick that originally flowed as a viscous lava southeast from its source near Scrugham Peak. As many as three tongues of lava are superimposed locally, each exhibiting a sequence of vesicular basalt over dense basalt over a thin vesicular base. In three dimensions it is seen that strata are arranged as nested cylinders sheathing the individual lava tongues.

The basalt has been divided into five groups based on vesicle

content. These groups and corresponding type designations used in laboratory studies are: vesicular basalt with more than 20 percent dispersed subspherical vesicles (Type V), vesicular basalt with 10 to 20 percent flattened vesicles in discontinuous layers (Types III and IV), vesicular basalt with 2 to 10 percent vesicles in layers (Type II), and dense basalt with up to 2 percent dispersed vesicles (Type I).

Average dry bulk specific gravity ranges from about 2.3 for Type V basalt to about 2.7 for Type I basalt. Static unconfined compressive strengths for six samples range from about 7,000 to 17,000 psi. Tangent moduli of elasticity determined on basalt from a nearby hole range between 2.3×10^6 and 6.6×10^6 psi.

Failure envelopes constructed on the basis of both triaxial compression tests and double direct shear tests give ϕ values of about 35 to 50 degrees for Type I basalt and about 20 degrees for Type V basalt with values of cohesion of 3,500 to 8,000 psi for Type I basalt and 3,500 psi for Type V basalt.

Triaxial compression tests were conducted on 7 samples with joints inclined at about 65 degrees to the major principal planes. The stress at first slip appears to be increased by increases in confining pressure, roughness of joint, and strength due to healing.

Sonic and ultrasonic tests suggest that dynamic Poisson's ratio lies in the range of 0.20 to 0.29, Young's modulus of

elasticity is about 4×10^6 to 8×10^6 psi, and modulus of rigidity is about 1.9×10^6 to 3.2×10^6 psi for Types I through III basalt.

Seismic field studies along a nearby traverse showed average compression wave velocities of about 1,000 ft/sec in the soil layer and 4,000 in the vesicular basalt below. From these values the velocity apparently increases to average values of about 13,000 and 16,000 ft/sec in slightly vesicular and dense basalt (Types III and I basalt), respectively, as indicated by laboratory tests. Vibratory field measurements suggest average shear wave velocities of about 700 ft/sec in the soil layer and 1,300 ft/sec in the upper basalt (presumably Type V basalt). Effective porosity calculated from joint openings is about 1 percent.

Structure determined in borehole photographs and the walls of calyx holes consists of flow-layered basalt types arranged as flattened, nested cylinders with gradational contacts. At the Dugout site two cylinders are evident, an older one with axis corresponding to flow toward the northeast and a crosscutting cylinder with axis indicating flow toward the southeast.

This cylindrical structure along with numerous minor flow folds arranged parallel and across the cylinder axis establishes a simple orthogonal flow structure pattern for the entire site. Joints and blast fractures tend to parallel the flow layers, and as a result some of the blast effects are modified by the primary flow

pattern and the system of joints. The dominant structural element with regard to cratering is believed to be a system of major vertical joints in two sets striking northeast and northwest normal to the flow cylinder axes. Spacing between these joints is about 5 feet.

The charge was detonated on 24 June 1964, and it formed an elliptical apparent crater about 135 feet wide, 285 feet long, and 35 feet deep. The displaced preshot ground surface below ejecta is uplifted from 3 to 12 feet in the trench through the south lip. In the trench through the lip at the west end the maximum uplift is only 2 feet, and much of the displaced ground surface along the lip is below its preshot elevation.

The ejecta piled on this surface is up to 20 feet thick in the south trench and only about 10 feet thick in the west end trench. The thickness of fallback and ejecta decreases to its outer limit at a maximum of 500 feet from the row-charge location. The grain size also decreases outward generally. The bulk density of a large sample of ejecta excavated from the south trench was 119 pcf, equivalent to a bulking factor of 1.39.

The true crater, exposed by a trench extending into the crater, slopes at about 48 degrees on the south side and 54 degrees on the west end and presumably rounds at the bottom to a form approximating a paraboloid. At the preshot ground elevation the crater is 80 feet horizontally from the position of the row charge in the south

trench and in the west end trench 57 feet from the position of the nearest charge.

The rupture zone beyond the true crater can be subdivided into three zones of distinct types of deformation: the blast-fractured zone, the bulked zone, and the sheared zone (Figure 5.1). These three zones are partly superimposed. The zone of blast fracturing extends at least as far as 260 feet south of the position of the line of charges at a depth of 60 feet. This depth is apparently favorable for fracturing by virtue of stratigraphy or possibly crater mechanics. On the west end significant blast fracturing extends a maximum of 170 feet from the position of the end charge at the same favored depth of 60 feet.

The zone of bulking has much the same configuration as the blast-fractured zone and probably extends about 260 feet to the south. Effective porosities of as much as 14 percent were computed for short intervals of NCG 46 at a distance of 120 feet from the preshot position of the nearest charge.

A zone characterized by conspicuous shear deformation extends at least 160 feet from the end of the row charge. The diameters of the sand-filled calyx holes that penetrated this zone were on the average decreased in a direction N67E and increased in a direction N23W. This strain ellipse does not coincide with that expected in response to a compressive shock wave propagated west from the charges.

The explanation of this anomaly is apparently to be found in the structural anisotropy of the site. Most of the observed permanent strain has taken place by shear along the set of major vertical joints striking northeast.

The upper 44-foot portion of the media below the true crater lip at the west end exhibits relative craterward offset with respect to material immediately below, along several flat fractures. Offsets along individual fractures in U18M are as large as 3 inches. In the nearby trench, the apparent deformation at the edge of the crater has been an opening of fissures accompanying a craterward slumping that occurred while the mass was still endowed with kinetic energy from the blast. Similar information obtained during other crater studies indicates that materials in the lower portion of the fallback zone and in the rupture zone are displaced toward the crater opening. The reasons for relative and net displacements toward the crater are not clearly understood. The nature and cause of such displacements will be explored during future investigations of the engineering properties of craters.

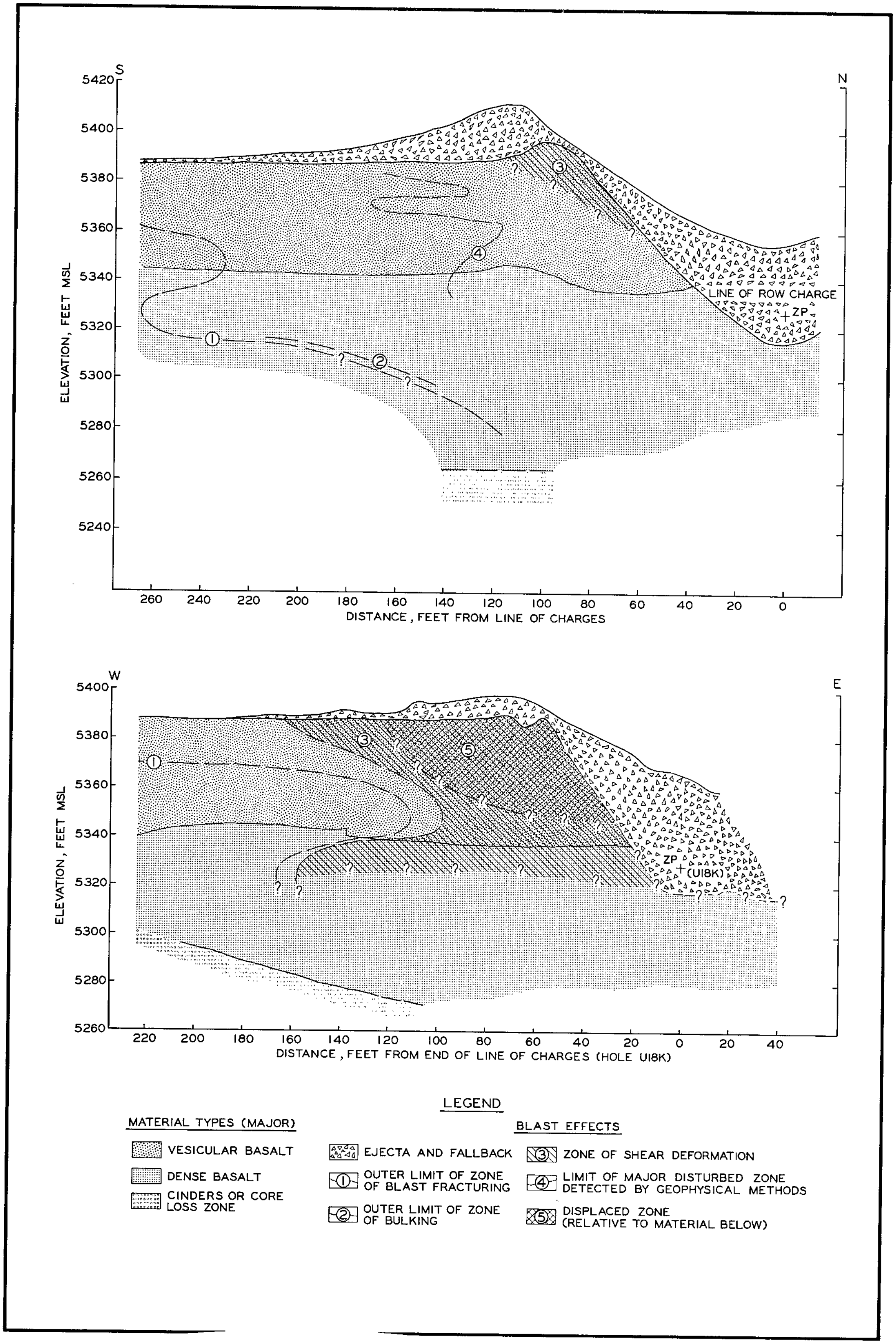


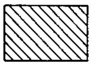
Figure 5.1 Zones of rupture and deformation adjacent to the Dugout crater.

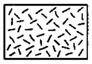
APPENDIX A

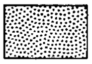
PRESHOT BORING LOGS

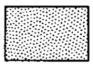
LEGEND FOR APPENDIX A

LITHOLOGY

 SOIL

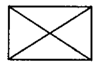
 VESICULAR BASALT, WITH 20 PERCENT VESICLES OR MORE

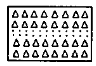
 VESICULAR BASALT, WITH 10 TO 20 PERCENT VESICLES

 VESICULAR BASALT, WITH 2 TO 10 PERCENT VESICLES

 DENSE BASALT, WITH UP TO 2 PERCENT DISPERSED VESICLES

 DENSE BASALT, NON-VESICULAR

 CORE LOSS ZONE

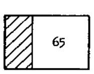
 TUFF BRECCIA OR TUFFACEOUS SANDSTONE

ABBREVIATIONS

BLDRS	BOULDERS	JTD	JOINTED
BLK	BLACK	O	OPEN
BRN	BROWN	OCC	OCCASIONAL
CAL	CALCITE	OX	OXIDIZED
CT	COATED	PF	PARTIALLY FILLED
DEG	DEGREES	SCAT	SCATTERED
DK	DARK	SEV	SEVERAL
F	FILLED	SL	SLIGHTLY
FRAG	FRAGMENTS	STRAT	STRATIFIED
GRY	GRAY	VES	VESICLES
H	HAIRLINE	W/	WITH
HD	HARD	WH	WHITE
HORIZ	HORIZONTAL	WTHRD	WEATHERED

* SUPPLEMENTARY JOINT DATA OBTAINED FROM CORE LOG.

CORE RECOVERY



CORE RECOVERY IN PERCENT; CORE LOSS INDICATED GRAPHICALLY BY SHADING

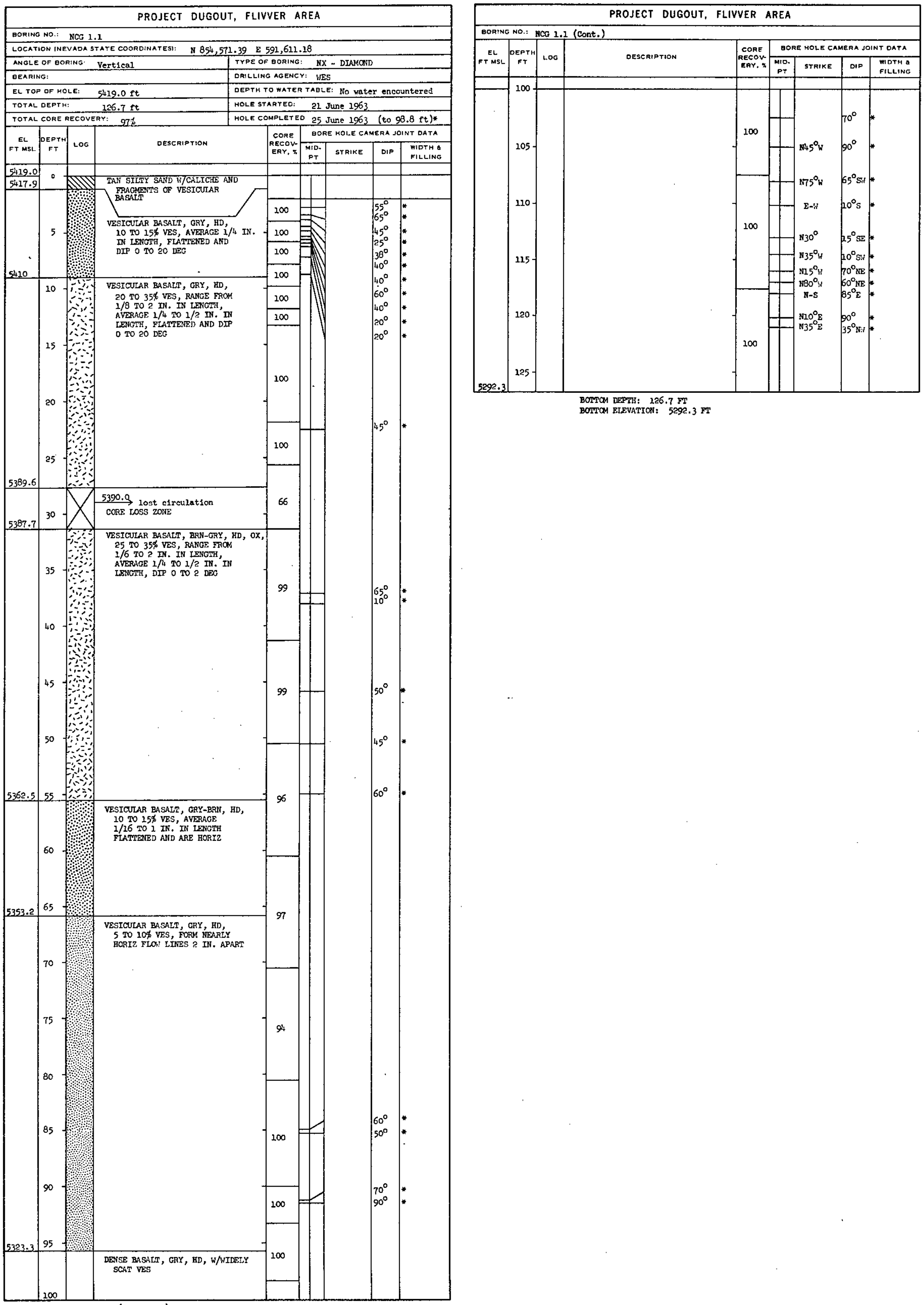


Figure A.1 Log of core Boring NCG 1.1.

PROJECT DUGOUT, FLIVVER AREA

BORING NO.: NCG 1.2	
LOCATION (NEVADA STATE COORDINATES): N 854,558.83 E 591,437.33	
ANGLE OF BORING: Vertical	TYPE OF BORING: NX - DIAMOND
BEARING:	DRILLING AGENCY: WES
EL TOP OF HOLE: 5416.7 ft	DEPTH TO WATER TABLE: No water encountered
TOTAL DEPTH: 120.0 ft	HOLE STARTED: 21 February 1964
TOTAL CORE RECOVERY: 99%	HOLE COMPLETED: 22 February 1964

EL FT MSL	DEPTH FT	LOG	DESCRIPTION	CORE RECOVERY, %	BORE HOLE CAMERA JOINT DATA: MID-PT	STRIKE DEG	DIP DEG	WIDTH & FILLING
5416.7	0		TAN SILTY SAND W/CALICHE AND FRAGMENTS OF VESICULAR BASALT					
5413.7			Top of Rock			N35E	35SE	1/8", F
			VESICULAR BASALT, DK GRY, HD, 20 TO 25% VES, RANGE FROM 1/16 TO 1/4 IN. IN LENGTH W/RANDOM ORIENTATION	73		EW	50N	3/8", F
	5					N50E	90	1/8", F
				83		N65W	50SW	3/8", F
						N25E	55NW	1/16", F
5405.3				86		N-S	60W	1/16", F
	10		VESICULAR BASALT, GRY, HD, 5 TO 10% VES, RANGE FROM 1/16 TO 1 IN. IN LENGTH, AND UP TO 1/2 IN. IN WIDTH	100		N45E	90	H
						N35E	90	1/32", F
						N35E	10SE	1/16", F
	15		15% ves			N05E	90	H
			10 ft, ves layers strike N20°W, dip 35°SW	100		N-S	10W	1/16", O
						N-S	90	H
			15 ft, ves layers horizontal			N05E	30E	1/16", F
							0	1-1/2", Pf
5396.3	20		20 ft, ves layers strike NS, dip 05°W			N25W	05NE	3/4", Pf
			VESICULAR BASALT, GRY, HD, 15 TO 20% VES, RANGE UP TO 1 IN. IN LENGTH, AND 1/4 TO 1/2 IN. IN WIDTH			N30W	35NE	1/8", F
							0	1/4", F
	25						0	1", Pf
			25 ft, ves layers strike EW, dip 15°N	100				
						N60W	90	H
	30		30 ft, ves layers strike NS, dip 05°W			N35E	80SE	1/16", Pf
				100				
	35		5381.7 → lost circulation			N55W	90	H
			35 ft, ves layers strike N10°W, dip 05°NE					
	40			100				
						N20E	05NW	1/16", Pf
						N60E	10NW	1/16", Pf
						N40W	55SW	H
	45		45 ft, ves layers strike N65°W, dip 25°NE			E-W	20N	3/4", Pf
				100				
	50		dense basalt					
						N10W	30SW	1-1/2" Pf
	55		55 ft, ves layers horizontal			N20E	80SE	3/8", Pf
				100		N45E	15NW	1/16", Pf
			60 ft, ves layers strike N20°E, dip 10°NW			N25E	20NW	1/8", Pf
5356.6	60					N60E	30SE	1", Pf
			VESICULAR BASALT, GRY, HD, 5% VES.					
	65		65 ft, ves layers horizontal	100				
	70		70 ft, ves layers strike N35°E, dip 10°NW					
5343.5			DENSE BASALT, GRY, HD, W/WIDELY SCAT VES					
	75		75 ft, horizontal ves layers	100				
	80		80 ft, ves layers strike N05°W, dip 30°SW					
				100				
	85		85 ft, ves layer strikes N30°W, dips 20°SW			N15W	35NE	1/8", F
						N20E	30NW	1/16", F
	90		90 ft, ves layer strikes N20°W, dips 40°SW	100				
						N10E	30NW	1/16", F
	95		95 ft, ves layer strikes N25°W, dips 45°SW					
	100		100 ft, ves layer strikes N25°W, dips 60°SW			N20W	45SW	1/16", F

(Continued)

PROJECT DUGOUT, FLIVVER AREA

BORING NO.: NCG 1.2 (Cont.)

EL FT MSL	DEPTH FT	LOG	DESCRIPTION	CORE RECOVERY, %	BORE HOLE CAMERA JOINT DATA: MID-PT	STRIKE DEG	DIP DEG	WIDTH & FILLING
	100			100		E-W	65N	1/16", F
						N25W	60SW	1/16", O
	105					N45W	60SW	1/8", F
	110			100				
						N25W	65SW	*
						N70E	40NW	*
							0	*
	115					N60E	70NW	*
						N40W	25SW	*
				100				
5296.7	120							

BOTTOM DEPTH: 120.0 FT
BOTTOM ELEVATION: 5296.7 FT

Figure A.2 Log of core Boring NCG 1.2.

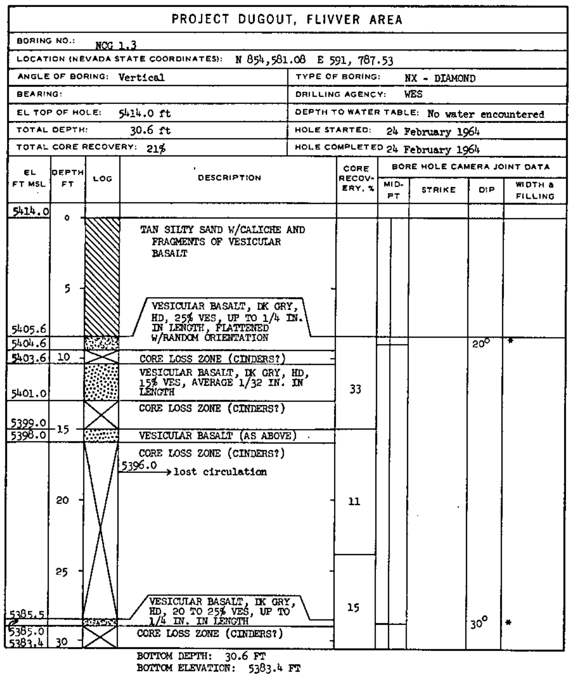


Figure A.3 Log of core Boring NCG 1.3.

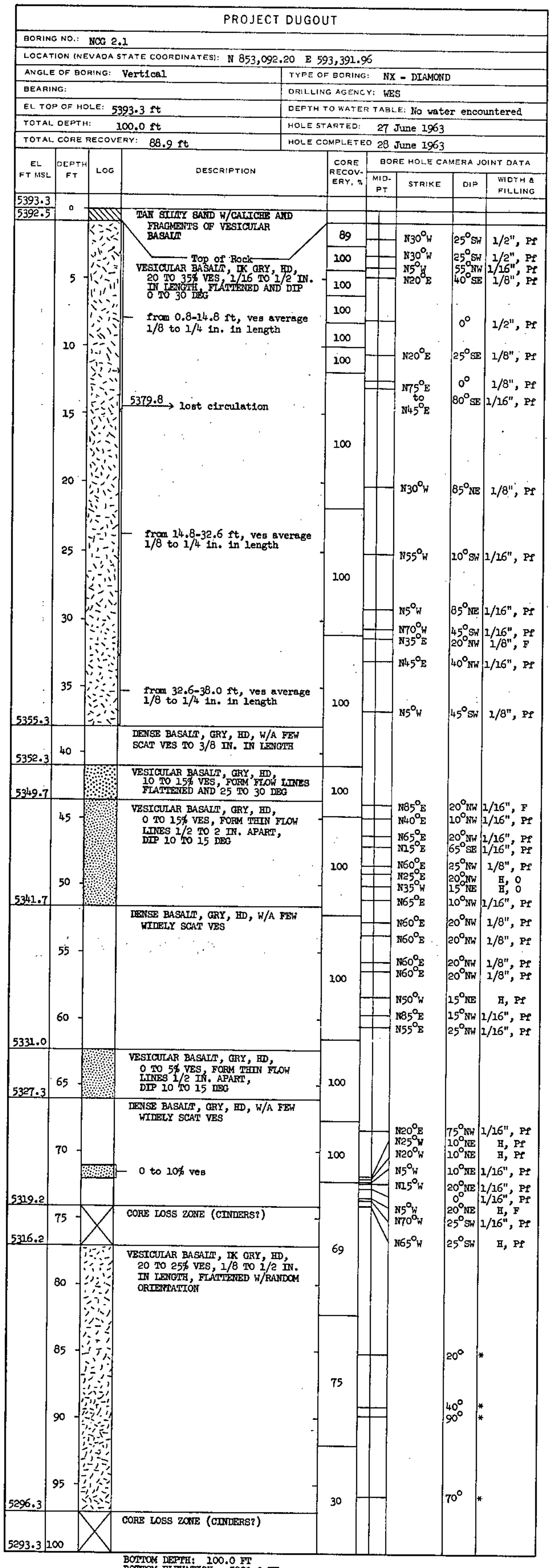


Figure A.4 Log of core Boring NCG 2.1

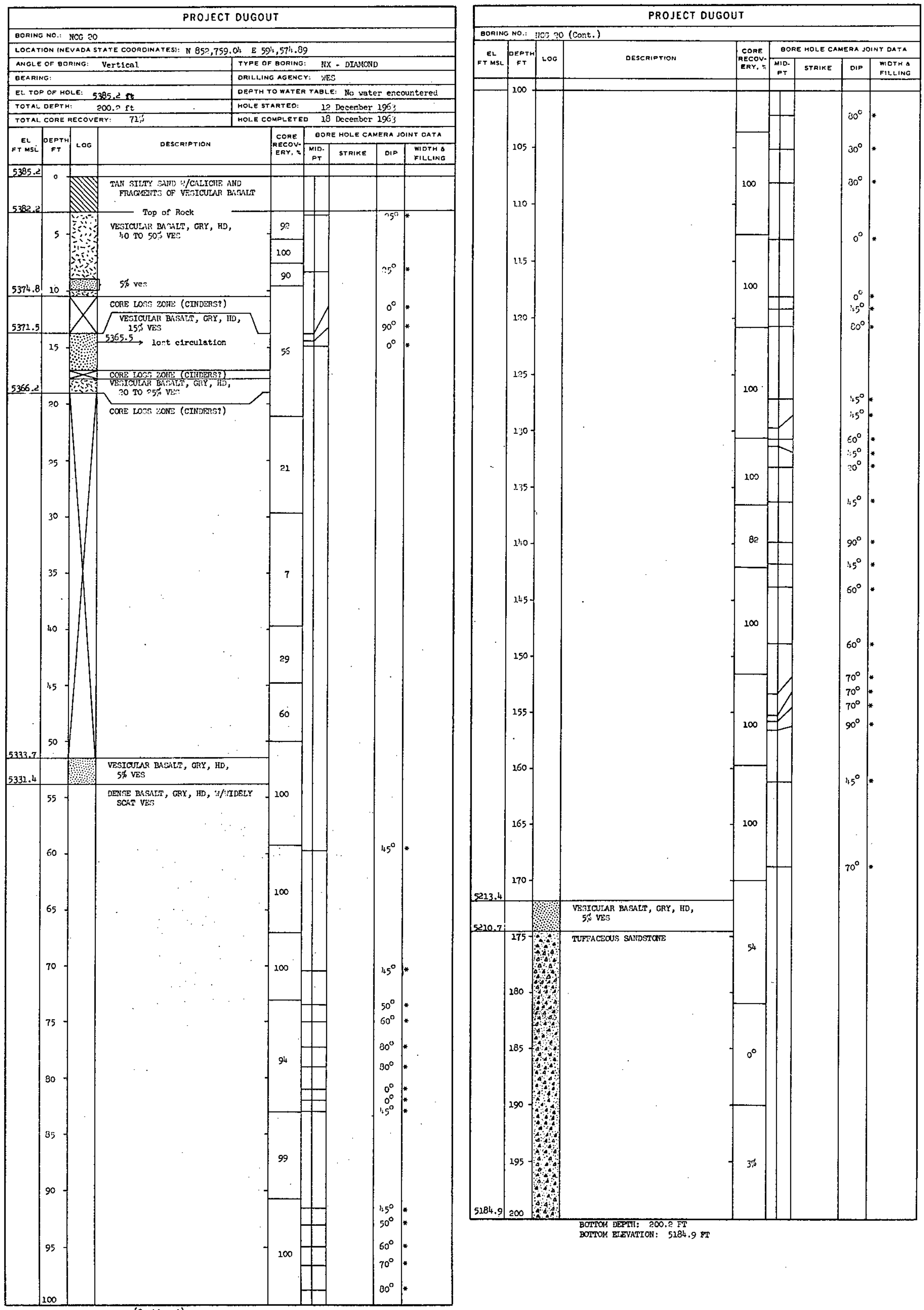


Figure A.5 Log of core Boring NCG 20.

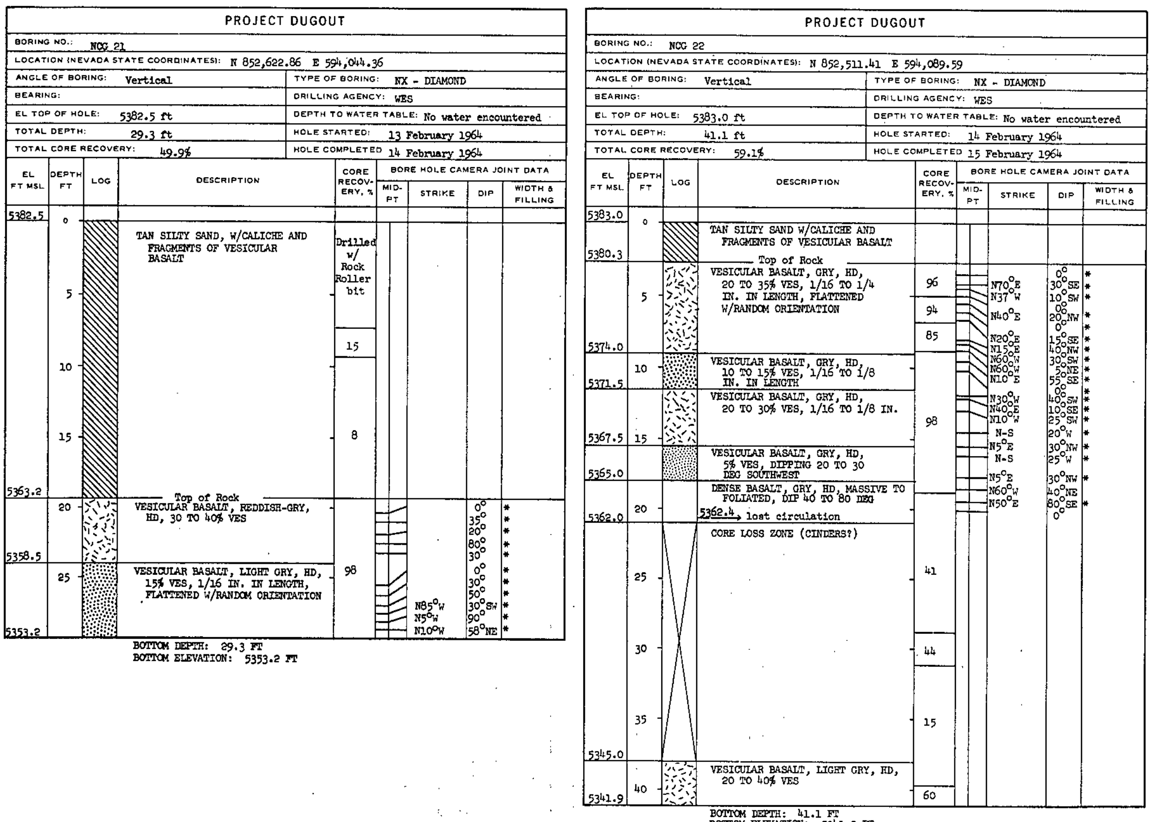


Figure A.6 Logs of core Borings NCG 21 and NCG 22.

PROJECT DUGOUT

BORING NO.: NCG 23	
LOCATION (NEVADA STATE COORDINATES): N 852, 795.41 E 594,122.02	
ANGLE OF BORING: Vertical	TYPE OF BORING: NX - DIAMOND
BEARING:	DRILLING AGENCY: WES
EL TOP OF HOLE: 5384.7 ft	DEPTH TO WATER TABLE: No water encountered
TOTAL DEPTH: 121.4 ft	HOLE STARTED: 16 February 1964
TOTAL CORE RECOVERY: 91%	HOLE COMPLETED 19 February 1964

EL FT MSL	DEPTH FT	LOG	DESCRIPTION	CORE RECOVERY, %	BORE HOLE CAMERA JOINT DATA: MID-PT	STRIKE	DIP	WIDTH & FILLING
5384.7	0		TAN SILTY SAND W/CALICHE AND FRAGMENTS OF VESICULAR BASALT					
5382.8			Top of Rock					
			VESICULAR BASALT, GRY, HD, 20 TO 30% VES, AVERAGE 1/16 TO 1/8 IN. IN WIDTH, FLATTENED AND DIP 0 TO 30 DEG	100			0°	*
	5			100			30°	*
							70°	*
						N70°W	55°NE	*
				100		N-S	90°	*
				100		N55°E	60°SE	*
						N50°E	40°NW	*
	10						60°	*
				100			10°	*
							45°	*
							55°	*
	15						15°	*
							25°	*
				96		N80°E	40°NW	*
	20					N5°W	30°NE	*
						N15°W	25°NE	*
						N5°E	20°NW	*
	25			100				
	30							
			5% ves				10°	*
	35			99			20°	*
							70°	*
			dense basalt				20°	*
5344.7	40		VESICULAR BASALT, GRY, HD, 0 TO 10% VES, FLATTENED AND DIP 0 TO 10 DEG					
	45			100		N20°E	10°SE	*
							0°	*
						N50°W	35°NE	*
5334.7	50		DENSE BASALT, MASSIVE, GRY, HD, W/A FEW WIDELY SCAT VES	100				
						N45°E	10°SE	*
	55			100		N45°W	60°NE	*
						N45°W	70°SW	*
	60							
	65			100				
	70							
							55°	*
							55°	*
	75			88			60°	*
	80							
	85			100		N70°W	70°NE	*
							25°	*
							70°	*
	90			97			50°	*
						N45°E	10°NW	*
						N40°E	10°NW	*
						N80°W	40°NE	*
5290.2						N-S	20°W	*
	95		CORE LOSS ZONE (CINDERS?)	73		N80°W	30°SW	*
5287.4			VESICULAR BASALT, BROWN TO RED GRY, HD, 30% VES AVERAGE 1/16 IN. IN WIDTH				50°	*
	100					N50°E	35°NW	*

(Continued)

PROJECT DUGOUT

BORING NO.: NCG 23 (Cont.)

EL FT MSL	DEPTH FT	LOG	DESCRIPTION	CORE RECOVERY, %	BORE HOLE CAMERA JOINT DATA: MID-PT	STRIKE	DIP	WIDTH & FILLING
	100					N65°W	50°SW	*
							75°	*
5281.7							20°	*
5279.7			VESICULAR BASALT, RED, HD, 15% VES					
	105		CORE LOSS ZONE (CINDERS)	48				
5273.9	110		VESICULAR BASALT, RED-GRY, HD, 25% VES, 1/16 TO 1/4 IN. IN LENGTH					
	115			84			80°	*
							90°	*
	120			100		N85°W	20°SW	*
5263.3						N30°W	5°SW	*

BOTTOM DEPTH: 121.4 FT
BOTTOM ELEVATION: 5263.3 FT

Figure A. 7 Log of core Boring NCG 23.

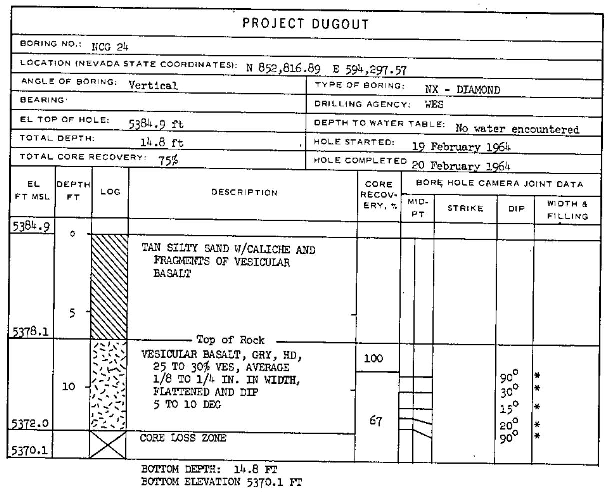


Figure A.8 Log of core Boring NCG 24.

PROJECT DUGOUT

BORING NO.: NCG 25	
LOCATION (NEVADA STATE COORDINATES): N 853,287.49 E 593,975.52	
ANGLE OF BORING: Vertical	TYPE OF BORING: NX - DIAMOND
BEARING:	DRILLING AGENCY: WES
EL TOP OF HOLE: 5386.8 FT	DEPTH TO WATER TABLE: No water encountered
TOTAL DEPTH: 120.3 FT	HOLE STARTED: 20 February 1964
TOTAL CORE RECOVERY: 96.5%	HOLE COMPLETED 22 February 1964

EL FT MSL	DEPTH FT	DESCRIPTION
5386.8	0	TAN SILTY SAND W/CALICHE AND FRAGMENTS OF VESICULAR BASALT
5383.7		Top of Rock
5383.4		CORE LOSS ZONE
	5	VESICULAR BASALT, GRY, HD, 20 TO 50% VES, AVERAGE 1/16 TO 1/2 IN. IN LENGTH AND 1/8 TO 1/4 IN. IN WIDTH DIP 0 TO 30 DEG
		30 to 50% ves
5351.8	35	VESICULAR BASALT, GRY, HD, 15% VES, FLATTENED W/RANDOM ORIENTATION
5348.0		VESICULAR BASALT, GRY, HD, 5% VES, AVERAGE 1/16 TO 1/8 IN. IN. LENGTH, FLATTENED AND DIP 0 TO 20 DEG
5336.8	50	DENSE BASALT, MASSIVE, GRY, HD, W/WIDELY SCAT VES
		5329.0 → lost circulation

CORE RECOVERY, %: 80, 40, 58, 100, 100, 100, 100, 100, 100, 98, 100, 100, 100, 97

BORE HOLE CAMERA JOINT DATA

STRIKE	DIP	WIDTH & FILLING
N10°E	10°NW	*
	35°	*
	10°	*
	45°	*
	35°	*
	15°	*
	0°	*
	35°	*
	65°	*
	40°	*
	30°	*
	15°	*
	85°	*
	40°	*
	60°	*
N80°E	90°	*
N65°E	20°NW	*
N80°W	45°SW	*
N-S	25°W	*
N70°W	65°SW	*
N40°W	25°NE	*
N-S	5°W	*
N-S	10°E	*
N5°W	25°NE	*
	55°	*
	30°	*
	80°	*
	40°	*
	55°	*
	35°	*
	50°	*
	35°	*
	30°	*
	50°	*
	80°	*
	70°	*
	65°	*
	75°	*
	60°	*
	85°	*
	40°	*
	50°	*
	70°	*
	80°	*
	20°	*
	35°	*

(Continued)

PROJECT DUGOUT

BORING NO.: NCG 25 (Cont.)

EL FT MSL	DEPTH FT	DESCRIPTION
	100	
5267.9		
5266.5	120	CORE LOSS ZONE (CINDERS?)

BOTTOM DEPTH: 120.3 FT
BOTTOM ELEVATION: 5266.5 FT

CORE RECOVERY, %: 100, 87

BORE HOLE CAMERA JOINT DATA

STRIKE	DIP	WIDTH & FILLING
	30°	*
	35°	*
	60°	*
	75°	*
	75°	*
N55°W	30°SW	*
N40°E	45°SE	*
E-W	50°N	*
N65°E	40°SE	*
N80°E	40°SE	*
N60°E	50°SE	*

Figure A.9 Log of core Boring NCG 25.

PROJECT DUGOUT

BORING NO.: NCG 26	
LOCATION (NEVADA STATE COORDINATES): N 853,289.83 E 594,149.94	
ANGLE OF BORING: Vertical	TYPE OF BORING: NX - DIAMOND
BEARING:	DRILLING AGENCY: WES
EL TOP OF HOLE: 5383.7 ft	DEPTH TO WATER TABLE: No water encountered
TOTAL DEPTH: 121.7 ft	HOLE STARTED: 22 February 1964
TOTAL CORE RECOVERY: 93%	HOLE COMPLETED: 25 February 1964

EL FT MSL	DEPTH FT	DESCRIPTION	CORE RECOVERY, %	STRIKE	DIP	WIDTH & FILLING
5383.7	0	TAN SILTY SAND W/CALICHE AND FRAGMENTS OF VESICULAR BASALT				
5379.7		Top of Rock				
	5	VESICULAR BASALT, RED TO GRY, HD, 20 TO 50% VES, AVERAGE 1/16 TO 1/2 IN. IN LENGTH, AND 1/16 TO 1/4 IN. IN WIDTH, FLATTENED AND DIP 10 TO 60 DEG	95	N20°E	50°SE	1/16", Pf
				N5°W	30°NE	1/16", Pf
			75	N65°W	30°SW	1/8", Pf
				N5°E	25°NW	1/4", Pf
					0°	1/4", Pf
			100	N85°E	25°NW	1/32", Pf
	10			N55°E	45°SE	1/16", Pf
				N60°W	30°NE	1/16", Pf
		5371.7 → lost circulation		N65°E	20°NW	1/2", Pf
				N65°W	90°	1/4", Pf
					0°	1/4", Pf
	15		97	N10°E	90°	1/4", Pf
					0°	1/4", Pf
				N10°E	20°SE	1/4", Pf
				N-S	45°E	1/2", Pf
	20			N10°W	20°SW	1/16", Pf
			100	N45°W	70°NE	1/16", Pf
				N25°E	60°NW	1/16", Pf
				N45°W	35°NE	1/2", Pf
	25					
			100	N50°E	30°SE	1/16", Pf
				N50°E	80°SE	1/16", Pf
	30					
					0°	1/32", Pf
					0°	1/32", Pf
	35			N80°W	5°SW	1/32", Pf
			100	N80°W	5°SW	1/8", Pf
				N30°E	5°SE	1/32", Pf
				N45°E	30°SE	1/32", Pf
	40			N45°W	45°NE	1", Pf
5342.0		VESICULAR BASALT, GRY, HD, 15% VES, AVERAGE 1/16 TO 1/8 IN. IN LENGTH, FLATTENED AND DIP 30 TO 40 DEG				
	45			N65°W	20°SW	1/4", Pf
				N10°E	60°SE	1/8", Pf
		dense basalt				
		20% ves	100	N5°E	80°NW	1/16", Pf
5333.7	50	VESICULAR BASALT, GRY, HD, 10% VES DIP 0 TO 20 DEG				
5331.7		DENSE BASALT, MASSIVE, GRY, HD, W/WIDELY SCAT VES			0°	1/8", Pf
				N25°E	45°NW	1/8", Pf
				N55°E	55°SE	1/16", Pf
	55			N35°E	55°NW	1/16", Pf
			100	N35°E	65°SE	1/16", Pf
				N55°E	45°NW	1/4", Pf
				N15°E	20°SE	1/16", Pf
	60			N10°E	5°NW	1/8", Pf
				N50°E	30°NW	1/4", Pf
				N50°E	5°NW	1/16", O
					0°	1/16", Pf
					0°	1/32", Pf
					0°	1/32", Pf
	65				0°	1/32", Pf
			100	N-S	5°W	1/32", Pf
				N10°E	5°NW	1/32", Pf
				N10°E	5°NW	1/16", Pf
				N5°W	20°NE	1/32", Pf
					0°	1/8", Pf
	70			N10°E	5°NW	1/32", Pf
					0°	1/32", Pf
				N85°E	20°NW	1/32", Pf
					0°	1/8", Pf
				N20°W	30°SW	1/32", Pf
				N20°W	5°NE	1/32", Pf
	75		100	N10°E	5°SE	1/4", Pf
					0°	1/32", Pf
				N5°W	80°NE	1/16", Pf
					0°	1/32", Pf
					0°	1/32", Pf
				N80°W	70°SW	1/4", Pf
	80				0°	1/4", Pf
				N5°E	40°NW	1/8", Pf
				N5°W	45°SW	1/4", Pf
				N85°W	65°SW	1/4", Pf
	85		99			
				N5°W	10°SW	1/16", Pf
				N85°W	85°NE	1/2", Pf
				N50°W	45°NE	1/16", Pf
5292.7	90			N80°E	45°SE	1/16", Pf
		CORE LOSS ZONE (CINDERS?)			0°	1/2", Pf
5290.0		VESICULAR BASALT, RED-GRY, HD, 25 TO 45% VES, AVERAGE 1/4 TO 1/2 IN. IN LENGTH, DIP 30 TO 60 DEG	76			
	95			N60°W	55°SW	1/2", Pf
				N10°E	90°	1/4", Pf
				N80°W	20°SW	1/16", Pf
				N75°W	60°SW	1/2", Pf
	100			N60°E	45°NW	1/4", Pf

(Continued)

PROJECT DUGOUT

BORING NO.: NCG 26 (Cont.)

EL FT MSL	DEPTH FT	DESCRIPTION	CORE RECOVERY, %	STRIKE	DIP	WIDTH & FILLING
	100			N10°E	80°SE	1/2", Pf
5281.1		CORE LOSS ZONE (CINDERS?)				
	105					
5277.9		VESICULAR BASALT, DK BRN-GRY, HD, 20 TO 30% VES, DIP 20 TO 70 DEG	61	N85°W	20°NE	1/32", Pf
				E-W	45°N	1/4", Pf
5272.6	110			N10°E	60°SE	1/16", Pf
		VESICULAR BASALT, GRY, HD, 15% VES, DIP 0 TO 10 DEG			80°	*
			83		45°	*
					40°	*
				N65°E	35°SE	1/16", Pf
5267.7	115			N25°E	25°NW	1/4", Pf
		DENSE BASALT, MASSIVE, GRY, HD, W/SCAT VES		N85°E	65°SE	*
			99	N35°W	85°NE	*
				N87°W	27°NE	*
	120					
5262.0				N65°W	15°NE	*

BOTTOM DEPTH: 121.7 FT
BOTTOM ELEVATION: 5262.0 FT

Figure A.10 Log of core Boring NCG 26.

PROJECT DUGOUT, FLIVVER AREA

BORING NO.: NCG 27	
LOCATION (NEVADA STATE COORDINATES): N 854,323.94 E 591,876.57	
ANGLE OF BORING: Vertical	TYPE OF BORING: NX - DIAMOND
BEARING:	DRILLING AGENCY: WES
EL TOP OF HOLE: 5419.1 ft	DEPTH TO WATER TABLE: No water encountered
TOTAL DEPTH: 120.0 ft	HOLE STARTED: 24 February 1964
TOTAL CORE RECOVERY: 99.7%	HOLE COMPLETED 29 February 1964

EL FT MSL	DEPTH FT	DESCRIPTION
5419.1	0	TAN SILTY SAND W/CALICHE AND FRAGMENTS OF VESICULAR BASALT
5417.6		Top of Rock
		VESICULAR BASALT, DK GRY, HD, 25 TO 30% VES, UP TO 1/2 IN. IN LENGTH, FLATTENED W/RANDOM ORIENTATION
	30	30 ft, ves layers strike N20°E, dip 35°NW
5387.0		VESICULAR BASALT, GRY, HD, 15% VES, RANGE FROM 1/16 TO 1/2 IN. IN LENGTH, DIP 20°NW
5382.7		VESICULAR BASALT, BRN-GRY, HD, 20% VES, RANGE 1/16 TO 3/4 IN. IN LENGTH, FEW VES UP TO 2 IN. IN LENGTH AND 1/2 IN. IN WIDTH, FLATTENED
	45	46 ft, ves layers strike N50°E, dip 30°NW
	50	51 ft, ves layers dip 05°W
	55	57 ft, ves layers dip 05°SW
		dense basalt w/scat ves
5358.9	60	VESICULAR BASALT, BRN-GRY, HD, 5 TO 10% VES,
	65	65 ft, ves layers strike N20°W, dip 10°NE
	70	70 ft, ves layers strike N85°W, dip 15°N
	75	75 ft, ves layers strike N65°W, dip 10°NE
	80	80 ft, ves layers horizontal
	85	85 ft, ves layers strike N40°W, dip 30°NE
	90	90 ft, ves layers strike N30°W, dip 20°NE
5319.5	100	100 ft, ves layers strike N15°E, dip 05°SE

CORE RECOVERY, %: 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100

BORE HOLE CAMERA JOINT DATA

STRIKE DEG	DIP DEG	WIDTH & FILLING
N55W	15SW	1/2", 0
	0	1", Pf
N40E	90	1/16", Pf
N20E	85SE	1/16", Pf
N25W	55NE	1/8", Pf
N35W	35SW	1/16", Pf
	0	1/16", Pf
N25E	45SE	1/16", Pf
N30E	55SE	1/16", Pf
	0	1/16", Pf
N20W	30SW	1/16", Pf
N20W	75SW	1/8", Pf
N50W	65NE	1/8", Pf
N65W	45NE	1/16", Pf
N60W	30NE	1/16", Pf
N40W	65SE	1/16", Pf
N70E	50NW	1/16", Pf
N10E	45NW	1/16", Pf
N30W	50SW	1/16", Pf
N-S	45E	H
N80W	10NE	1/8", Pf
N85E	60NW	H
N70E	40NW	H
N75E	40NW	H
N65W	65SW	1/16", Pf

(Continued)

PROJECT DUGOUT, FLIVVER AREA

BORING NO.: NCG 27 (Cont.)

EL FT MSL	DEPTH FT	DESCRIPTION
	100	DENSE BASALT, GRY, HD, W/WIDELY SCAT VES
	105	107 ft, ves layers strike N45°E, dip 50°NE
5299.1	120	

CORE RECOVERY, %: 96, 100, 100

BORE HOLE CAMERA JOINT DATA

STRIKE DEG	DIP DEG	WIDTH & FILLING
N20E	45SE	H
N10E	35SE	1/16", Pf
N75E	65NE	1/16", Pf
N70W	80SW	1/16", Pf
N50W	80SW	1/16", Pf
N45W	45SW	1/16", Pf
N30W	60SW	H
N25E	80SE	1/8", Pf
N60W	30NE	1/16", Pf

BOTTOM DEPTH: 120.0 FT
BOTTOM ELEVATION: 5299.1 FT

Figure A.11 Log of core Boring NCG 27.

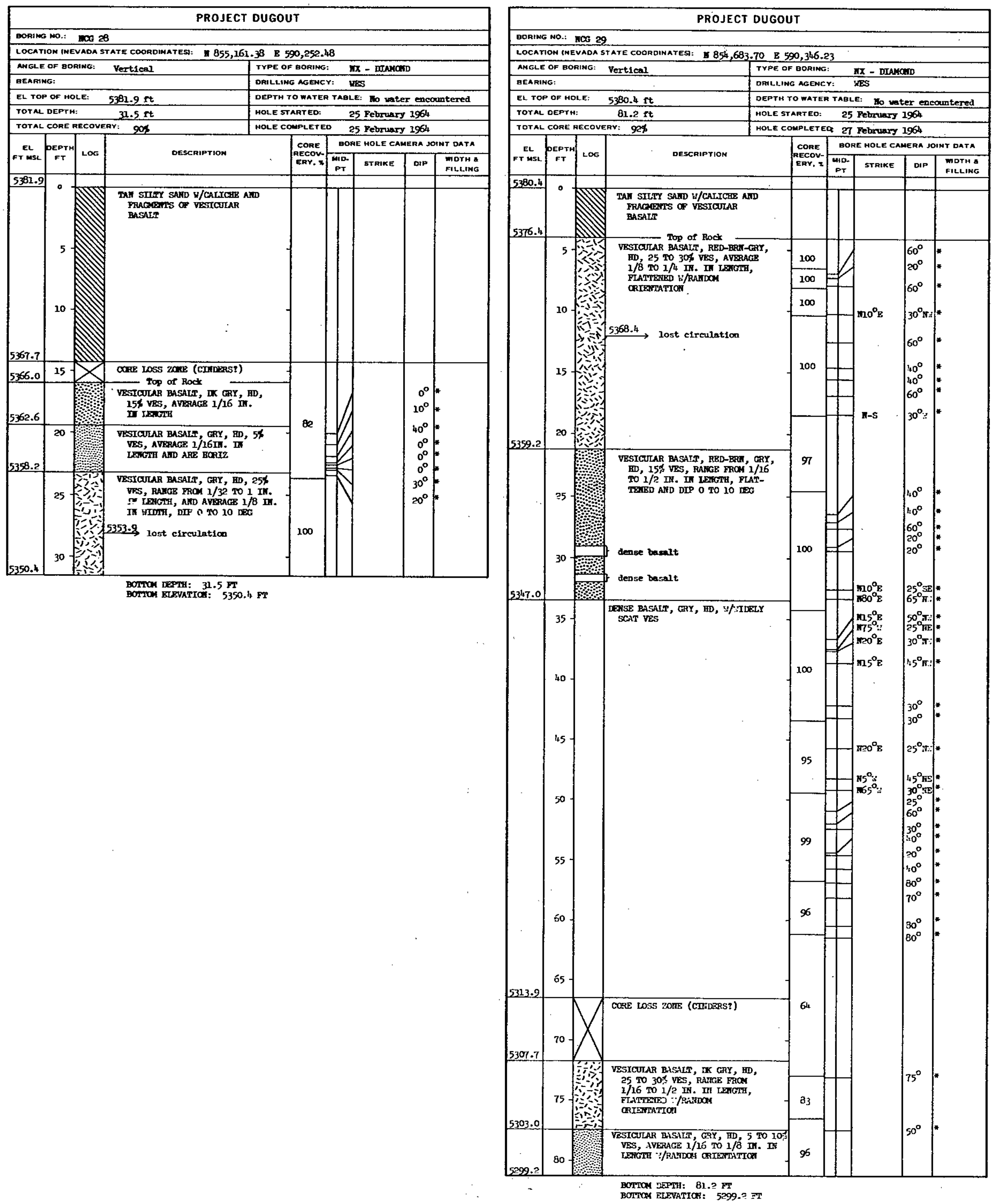


Figure A.12 Logs of core Borings NCG 28 and NCG 29.

PROJECT DUGOUT

BORING NO.: NCG 30	
LOCATION (NEVADA STATE COORDINATES): N 853,285.24 E 593,799.62	
ANGLE OF BORING: Vertical	TYPE OF BORING: NX - DIAMOND
BEARING:	DRILLING AGENCY: WES
EL TOP OF HOLE: 5388.5 ft	DEPTH TO WATER TABLE: No water encountered
TOTAL DEPTH: 120.8 ft	HOLE STARTED: 25 February 1964
TOTAL CORE RECOVERY: 93.4%	HOLE COMPLETED 27 February 1964

EL FT MSL	DEPTH FT	DESCRIPTION	CORE RECOVERY, %	BORE HOLE CAMERA JOINT DATA: STRIKE	DIP	WIDTH & FILLING
5388.5	0	TAN SILTY SAND W/CALICHE AND FRAGMENTS OF VESICULAR BASALT				
5384.0		Top of Rock				
	5	VESICULAR BASALT, DK GRY, HD, 20 TO 45% VES, AVERAGE 1/16 TO 1/4 IN. IN LENGTH, AND 1/16 TO 1/8 IN. IN WIDTH, FLATTENED AND DIP 0 TO 30 DEG	95		65°	*
					20°	*
					65°	*
			100		75°	*
			100	N40°E	45°NW	*
	10			N30°W	55°NW	*
			100	N30°W	85°NW	1/16", Pf
					30°	*
					45°	*
	15		99		35°	*
				N60°W	40°NE	1/16", Pf
	20		100	N65°W	60°SW	1/16", Pf
				N30°W	50°NE	1/16", Pf
					35°	*
		5364.5 → lost circulation				
	25			N20°W	80°SW	1/8", Pf
				N85°E	80°NW	1/16", Pf
			100	N80°W	10°SW	1/16", Pf
				N70°E	85°SW	1/16", Pf
				N20°W	85°NE	1/8", Pf
	30			N85°W	60°SW	1/8", Pf
					45°	*
					50°	*
5334.5	35	VESICULAR BASALT, GRY, HD, 15% VES, AVERAGE 1/8 IN. IN WIDTH, DIP 15 DEG NORTHWEST		N30°E	70°NW	1/8", Pf
			100	N-S	25°W	1/8", Pf
					0°	H, O
5350.5		VESICULAR BASALT, GRY, HD, 0 TO 10% VES, AVERAGE 1/16 TO 1/8 IN. IN WIDTH, DIP 0 TO 30 DEG			0°	H, O
	40			N85°W	10°NE	1/8", Pf
				N70°W	40°NE	1/16", Pf
	45		100			
				N60°W	45°SW	1/16", O
				N20°E	60°SE	1/16", Pf
	50			N60°E	80°SE	1/16", Pf
				N60°W	70°NE	1/16", Pf
5332.5	55		100	N55°W	55°NE	H, O
		DENSE BASALT, GRY, HD, W/WIDELY SCAT VES		N55°W	55°NE	H, O
	60			N40°W	80°SW	1/16", Pf
				E-W	35°S	1/16", Pf
			100	N40°E to N20°E	85°NW	1/8", Pf
	65				0°	1/16", Pf
					0°	1/16", Pf
	70		100	N85°W to N10°E	85°SW to 85°NW	H, F to 1/4", Pf
					0°	1/16", Pf
	75				0°	1/16", Pf
					0°	1/16", Pf
			100		0°	1/16", Pf
	80				0°	1/16", Pf
	85					
			100	N50°W	10°NE	H, F
				N50°W	10°NE	*
	90				0°	1/16", Pf
				N60°E	80°SE	1/16", Pf
	95		100		0°	H, F
	100			N85°W	35°NE	H, F

(Continued)

PROJECT DUGOUT

BORING NO.: NCG 30 (Cont.)

EL FT MSL	DEPTH FT	DESCRIPTION	CORE RECOVERY, %	BORE HOLE CAMERA JOINT DATA: STRIKE	DIP	WIDTH & FILLING
	100				0°	1/16", O
				N20°W	85°SW	1/16", Pf
					0°	1/16", O
					0°	1/16", O
	105		95	N45°W	80°NE	1/16", Pf
				N75°E	30°NW	H, F
				N75°E	30°NW	H, F
5278.7	110	CORE LOSS ZONE (CINDERS?)				
5272.7	115	VESICULAR BASALT, RED, HD, 25 TO 35% VES, AVERAGE 1/4 IN. IN WIDTH, W/RANDOM ORIENTATION	78			
5267.7	120					

BOTTOM DEPTH: 120.8 FT
BOTTOM ELEVATION: 5267.7 FT

Figure A.13 Log of core Boring NCG 30.

PROJECT DUGOUT, FLIVVER AREA	
BORING NO.: NCG 31	
LOCATION (NEVADA STATE COORDINATES): N 854,310.88 E 591,646.40	
ANGLE OF BORING: Vertical	TYPE OF BORING: NX - DIAMOND
BEARING:	DRILLING AGENCY: WES
EL TOP OF HOLE: 5418.7 ft	DEPTH TO WATER TABLE: No water encountered
TOTAL DEPTH: 120.2 ft	HOLE STARTED: 28 February 1964
TOTAL CORE RECOVERY: 98.5%	HOLE COMPLETED 29 February 1964

EL FT MSL	DEPTH FT	LOG	DESCRIPTION	CORE RECOVERY, %	BORE HOLE CAMERA JOINT DATA: MID-PT	STRIKE DEG	DIP DEG	WIDTH & FILLING
5418.7	0							
			TAN SILTY SAND W/CALICHE AND FRAGMENTS OF VESICULAR BASALT			N30W	65NE	1/16", F
5414.5						N-S	60W	1/16", Pf
			Top of Rock					
	5		VESICULAR BASALT, GRY, HD, 20 TO 40% VES, AVERAGE 1/16 TO 1/4 IN. IN WIDTH, FLATTENED AND DIP 0 TO 20°	70		N15W	65NE	1/8", Pf
						N85E	65SE	1/16", Pf
				55		N05W	45NE	1/8", Pf
						N05W	65SW	1/16", Pf
				86				
	10			95				
				100		N85E	45SE	H
						N75E	50NW	1/8", Pf
5404.2						N60E	60SE	H
	15		VESICULAR BASALT, GRY, HD, 15% VES, AVERAGE 1/8 IN. IN WIDTH FLATTENED AND DIP 40°NE	100		N60E	45NW	1/4", O
						N85E	30SE	H
						N60E	45NW	1/16", O
						N80W	35NE	1/16", O
5399.7						N80W	35NE	1/16", Pf
	20		5398.1 → lost circulation	100		N80E	50NW	1/8", Pf
						N70E	45NW	1/8", O
			VESICULAR BASALT, GRY, HD, 0 TO 10% VES, RANGE FROM 1/16 TO 1/2 IN. IN LENGTH, AND 1/16 TO 1/4 IN. IN WIDTH, FLATTENED	100		N45E	65SE	1/4", Pf
						N70E	25NW	1/16", Pf
	25					N65E	30NW	1/16", Pf
						N65E	30NW	1/16", Pf
				100		N85W	30NE	1/8", Pf
			20 ft, ves layers strike N70°E, dip 50°NW			N75E	20NW	1/16", Pf
						N50E	20NW	1/16", Pf
							0	1/4", Pf
	30		25 ft, ves layers strike N85°E, dip 35°NW			E-W	10N	H
						N45E	05NW	1/16", Pf
			30 ft, ves layers strike N85°W, dip 30°NE			E-W	30N	1/16", Pf
						N80E	30NW	1/16", Pf
						E-W	10N	1/16", Pf
	35		35 ft, ves layers strike N45°E, dip 20°NW			N60W	40NE	1/16", O
				100		N75E	15NW	1/16", O
	40		40 ft, ves layers strike N60°E, dip 20°NW					
						N05E	10NW	H
	45		45 ft, ves layers strike N15°E, dip 15°NW	100				
	50		50 ft, ves layers strike NS, dip 20°W. Second set: N65°W, 10°NE					
	55		55 ft, ves layers strike EW, dip 10°N	100		N60E	50SE	1/16", Pf
						N50E	55NW	1/16", Pf
							0	1/4", Pf
	60		60 ft, ves layers strike N30°E, dip 10°NW Second set: N65°W; 40°SW					
	65		65 ft, ves layers strike N50°W, dip 35°SW	100				
	70		70 ft, ves layers strike N75°W, dip 10°N					
				100			0	1/16", Pf
	75		75 ft, ves layers horizontal				0	1/8", O
						N54W	10SW	H
	80		80 ft, ves layers horizontal				0	1/8", Pf
				100		N40W	35NE	1/16", Pf
	85		85 ft, ves layers strike N15°W, dip 15°SW			N40W	10SW	H
							0	H
	90		90 ft, ves layers strike N35°W, dip 10°SW					
5326.7			DENSE BASALT, GRY, HD, W/WIDELY SCAT VES	100				
	95		95 ft, ves layers strike N30°W, dip 35°SW					
	100			100		N60W	35SW	1/16", Pf

(Continued)

PROJECT DUGOUT, FLIVVER AREA
BORING NO.: NCG 31 (Cont.)

EL FT MSL	DEPTH FT	LOG	DESCRIPTION	CORE RECOVERY, %	BORE HOLE CAMERA JOINT DATA: MID-PT	STRIKE DEG	DIP DEG	WIDTH & FILLING
	100							
			101 ft, ves layers strikes N40°W, dips 50°SW					
	105					N40W	60SW	H
				100				
			108 ft, ves layer strikes N70°W, dips 70°SW			N75W	80SW	1/8", Pf
	110							
	115			100				
			118 ft, ves layer strikes N60°W, dips 80°SW					
5298.5	120					N65W	80SW	H

BOTTOM DEPTH: 120.2 FT
BOTTOM ELEVATION: 5298.5 FT

Figure A.14 Log of core boring NCG 31.

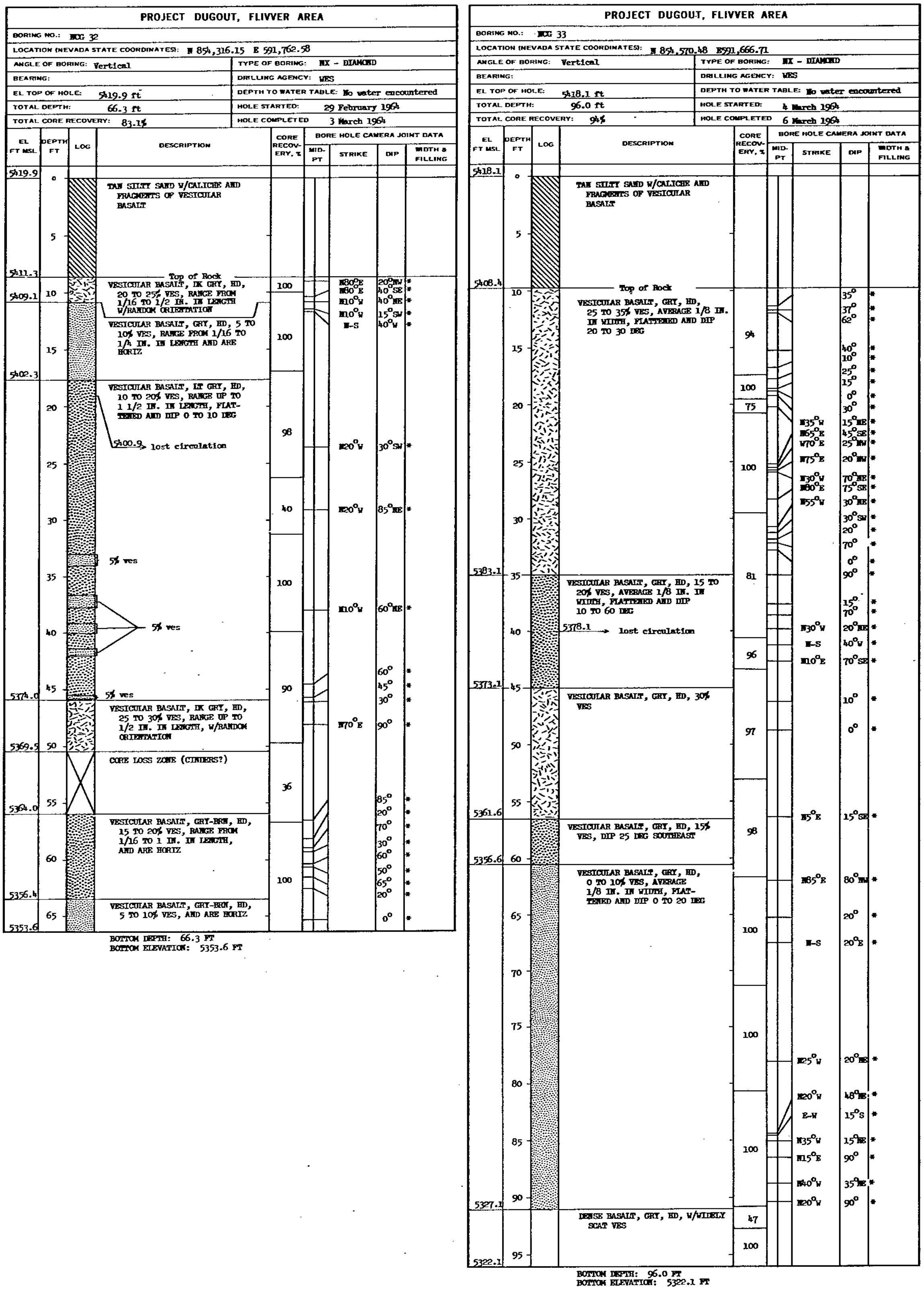


Figure A.15 Logs of core Borings NCG 32 and NCG 33.

PROJECT DUGOUT, FLIVVER AREA	
BORING NO.: NCG 34	
LOCATION (NEVADA STATE COORDINATES): N 854,315.3 E 591,752.6	
ANGLE OF BORING: Vertical	TYPE OF BORING: NX - DIAMOND
BEARING:	DRILLING AGENCY: WES
EL TOP OF HOLE: 5419.2 ft	DEPTH TO WATER TABLE: No water encountered
TOTAL DEPTH: 257.9 ft	HOLE STARTED: 6 March 1964
TOTAL CORE RECOVERY: 98%	HOLE COMPLETED: 12 March 1964

EL FT MSL	DEPTH FT	DESCRIPTION	CORE
5419.2	0	TAN SILTY SAND W/CALICHE AND FRAGMENTS OF VESICULAR BASALT	
5408.9	10	Top of Rock	
		VESICULAR BASALT, GRY, HD, 15 TO 20% VES, AVERAGE 1/8 IN. IN LENGTH, FLATTENED	100
			100
		15 ft, ves layers strike N25°W, dip 30°SW	100
			100
			100
			100
5397.2		VESICULAR BASALT, GRY, HD, 5 TO 10% VES, AVERAGE 1/8 IN. IN LENGTH FLATTENED	100
		5396.9 lost circulation	
		30 ft, ves layers strike N15°W, dip 15°SW	
		36 ft, ves layers strike N40°W, dip 20°NE	90
5380.2		VESICULAR BASALT, GRY, HD, 20 TO 30% VES, AVERAGE 1/4 IN. IN LENGTH, FLATTENED	100
		45 ft, ves layers strike N15°W, dip 40°NE	
5373.2		VESICULAR BASALT, GRY, HD, 15% VES, AVERAGE 1/16 IN. IN LENGTH	
		50 ft, ves layers strike N80°E, dip 10°N	
5368.2		VESICULAR BASALT, GRY, HD, 35% VES, AVERAGE 1/8 IN, IN WIDTH, FLATTENED	100
5361.2		VESICULAR BASALT, GRY, HD, 5 TO 10% VES, RANGE FROM 1/16 TO 1/8 IN. IN WIDTH	100
		66 ft, ves layers horizontal	
		75 ft, ves layers strike N45°E, dip 10°NW	100
5344.2	75	DENSE BASALT, GRY, HD, W/WIDELY SCATTERED VES	
		80 ft, ves layers strike NS, dip 10°W	100
		85 ft, ves layers strike N15°E, dip 5°SE	
		90 ft, ves layers strike N65°E, dip 10°SE	98
	100	100 ft, ves layers strike N55°E, dip 20°SE	

BORE HOLE CAMERA JOINT DATA

STRIKE DEG	DIP DEG	WIDTH & FILLING
N60E	45NW	1/16", Pf
N20E	30NW	1/16", Pf
N50E	35NW	1/8", Pf
	0	3/4", 0
N40E	45NW	1/16", 0
N05W	10SW	1/16", 0
N05E	65SE	1/16", 0
N10E	20W	1/16", Pf
N45W	90	1/16", Pf
N45W	90	1/16", Pf
N85W	10SW	3/4", Pf
N40E	05SE	1/16", Pf
N45W	80SW	1/16", Pf
N30E	70SE	1/16", Pf
N15W	80NE	1/4", Pf
N50E	85NW	1/4", Pf
	0	H
N40E	90	0
N50W	65SW	1/16", 0
N25E	50NW	1/16", 0
N60E	40NW	1/16", 0
N70E	80SE	1/8", Pf
N55W	30NE	1/16", 0
N70W	45SW	1/16", 0
N70W	80SW	1/16", 0
N60W	90	1/8", Pf
N65W	45NE	1/16", Pf
	0	
N70W	30SW	1/16", 0
N30W	60NE	H
N20W	25NE	H

(Continued)

PROJECT DUGOUT, FLIVVER AREA
BORING NO.: NCG 34 (Cont.)

EL FT MSL	DEPTH FT	DESCRIPTION	CORE
	100		98
		5% ves in layers that strike N75°W, dip 45°SW	100
			100
			100
			100
			100
			100
		ves dip 20°, red tint	100
		ves dip 10 to 20°SE	100
		3% ves, dip 5 to 10° Second set: N10°E, 80°NW	100
		1% ves, dip 10°	100
	200		99

BORE HOLE CAMERA JOINT DATA

STRIKE DEG	DIP DEG	WIDTH & FILLING
N50W	90	1/8", F
N35E	35SE	1/8", Pf
N45E	65SE	1/16", 0
N60W	80SW	1/8", 0
N60E	35SE	1/16", 0
N45W	45NE	1/16", 0
N30W	60NE	1/8", Pf
N20E	10SE	1/16", 0
N80W	20SW	1/16", 0
N55W	45NE	1/16", 0
N85W	90	1/16", 0
N30W	75NE	1/16", 0
N40W	35SW	1/16", 0
N55W	25SW	1/16", 0
N45W	45NE	H
N70E	35NE	H
N35E	65SE	1/16", 0
N30W	80NE	1/8", Pf
N15E	85SE	1/16", 0
N50W	15SW	H
N75E	50NW	1/8", 0
N65E	70NW	H
N45E	85NW	1/8", 0
N45W	10NE	1/16", 0
N50W	50SW	H
N35W	80SW	H
N45W	90	1/16", Pf
N45W	70NE	1/8", Pf
N45W	15NE	H
N60W	30NE	H
N45E	50SE	1/16", 0
N50E	05SE	1/16", 0
N15W	60SW	1/16", F
N15E	60NW	1/16", 0
N10E	20NW	1/16", 0
N70W	45NE	1/16", F
N35W	80SW	1/8", Pf
N50W	80SW	1/8", Pf
N45E	15SE	1/8", 0
N60W	70NE	1/16", 0
N70W	70NE	1/16", Pf
N-S	10E	1/16", Pf
N55W	65NE	1/16", F
N45E	80NW	1/16", Pf
N20E	90	1/8", Pf
N45E	85NW	1/16", 0
N50W	50SW	1/16", 0
N45W	35SW	1/16", 0
N05W	75SW	1/16", Pf
N20W	75NE	1/16", Pf
N20E	80SE	1/16", Pf
N20E	60NW	1/16", Pf
N-S	40W	1/16", Pf
N05E	55W	1/16", Pf
N60E	45NW	1/8", 0
N60E	55NW	1/8", Pf
N60E	45NW	1/8", Pf
N25W	30SW	1/16", Pf
N45W	40NE	1/16", Pf
E-W	40S	1/16", Pf
N25E	40SE	1/16", Pf
N45E	50SE	1/16", Pf
E-W	60S	1/16", Pf
N10E	50NW	1/16", Pf
N55W	50NE	1/16", 0
N65E	75SE	H
N25W	65SW	H
N60W	45SW	H
N60E	20SE	1/16", Pf
N70W	85SW	1/16", Pf
N50E	10SE	1/16", F
N10W	60SW	1/16", Pf
N10E	70SE	1/16", Pf
N45E	55SE	1/16", Pf
N20E	30NW	1/16", Pf

(Continued)

Figure A.16 Log of core Boring NCG 34.

PROJECT DUGOUT, FLIVVER AREA

BORING NO.: NCG 34 (Cont.)

EL FT MSL	DEPTH FT	DESCRIPTION	CORE RECOVERY, %
	200		100
			98
			97
			100
5178.2		VESICULAR BASALT, RED-GRY, HD, 50% VES, SOME CINDERY MATERIAL AND CORE LOSS	75
5171.2		TUFFACEOUS SANDSTONE, MEDIUM GRAINED, REDDISH TAN, LITHIC FRAGMENTS OF WIDE SIZE RANGE	69
5161.7			

BORE HOLE CAMERA JOINT DATA

STRIKE DEG	DIP DEG	WIDTH & FILLING
N15W	70SW	1/16", Pf
E-W	70N	1/16", Pf
N35W	60SW	1/16", O
N35E	50NW	1/16", Pf
N05W	10NE	H
N45W	45NE	H
N15E	10SE	H
N10E	75SE	H
N70W	85NE	1/16", Pf
N45W	20SW	1/16", F
N40E	50SE	H
N65W	45NE	H
N55W	45NE	H
N60W	45NE	H
	0	H
	0	H
N75W	20NE	H
N05W	10NE	H
N-S	05E	H
N-S	05E	H
N20W	10NE	H
N15E	10SE	H
N15E	10SE	H
N-S	05E	H
N-S	20E	H
N-S	20E	H
N30E	70NW	1/4", F
	0	1/16", F
N05W	10SW	1/8", F
N45W	30NE	H
N-S	10E	H
N55E	85SE	H
N85E	45NW	1/16", F
N30E	60NW	1/16", Pf
N25E	80SE	1/16", Pf
N40W	70NE	1/16", F
N45E	60NW	1/16", F

BOTTOM DEPTH: 257.9 FT
BOTTOM ELEVATION: 5161.7 FT

PROJECT DUGOUT

BORING NO.: NCG 35	
LOCATION (NEVADA STATE COORDINATES): N 853,289.8 E 593,909.9	
ANGLE OF BORING: Vertical	TYPE OF BORING: NX - DIAMOND
BEARING:	DRILLING AGENCY: WES
EL TOP OF HOLE: 5387.5	DEPTH TO WATER TABLE: No water encountered
TOTAL DEPTH: 80.0 ft	HOLE STARTED: 12 March 1964
TOTAL CORE RECOVERY: 96.6%	HOLE COMPLETED 14 March 1964

EL FT MSL	DEPTH FT	DESCRIPTION	CORE RECOVERY, %
5387.5	0	TAN SILTY SAND W/CALICHE AND FRAGMENTS OF VESICULAR BASALT	
5380.2		Top of Rock	
		VESICULAR BASALT, GRY, HD, 25 TO 35% VES, AVERAGE 1/16 TO 1/8 IN. IN WIDTH, FLATTENED AND DIP 0 TO 20 DEG	76
			87
			100
		5359.0 lost circulation	100
			100
			100
5342.5	45	VESICULAR BASALT, GRY, HD, 5% VES, AVERAGE 1/16 IN. IN WIDTH, FLATTENED AND DIP 0 TO 30 DEG	
			100
5331.5		DENSE BASALT, GRY, HD, W/WIDELY SCAT VES	100
			93
			83
5307.5	80		

BORE HOLE CAMERA JOINT DATA

STRIKE	DIP	WIDTH & FILLING
N25°W	20°NE	*
N55°W	45°SW	*
N75°W	90°	*
N85°E	45°SE	*
N75°E	45°SE	1/8", Pf
N85°E	30°NW	1/8", Pf
N20°W	15°NE	1/8", Pf
N-S	90°	1/16", Pf
	0°	1/2", Pf
N75°W	80°NE	1/16", Pf
N10°E	90°	1/16", Pf
	0°	1/8", Pf
N-S	80°W	1/16", Pf
N45°E	20°SE	1/8", Pf
N5°E	85°SE	1/16", Pf
N45°E	25°NW	1/8", Pf
N65°E	15°SE	1/16", Pf
	0°	1/8", Pf
N70°W	5°NE	1/16", Pf
N15°W	10°SW	1/2", Pf
N85°E	60°SE	1/8", O
N65°W	30°NE	1/8", Pf
N65°W	30°NE	H, F
N65°W	30°NE	1/8", Pf
N85°W	20°NE	H, F
N30°W	60°NE	1/8", Pf
50°E	20°NW	1/32", Pf
N70°E	50°SE	1/8", Pf
N-S	60°W	1/8", Pf
N30°W	60°NE	1/16", Pf
N35°E	60°NW	1/8", Pf
N55°E	55°SE	1/16", Pf
N20°E	70°NW	1/16", Pf
N5°W	45°NE	1/16", Pf
N80°W	80°NE	H, F
N45°E	50°NW	H, F
N5°W	40°NE	H, F
N35°E	65°SE	1/32", F
N65°W	50°SW	1/32", Pf
N5°W	55°SW	1/32", Pf
N70°W	35°SW	1/8", Pf
N70°W	45°SW	1/8", Pf
N10°W	80°NE	1/32", Pf
N5°E	80°SE	1/4", Pf
E-W	65°S	*
N-S	20°E	*
	35°	*
	15°	*

BOTTOM DEPTH: 80.0 FT
BOTTOM ELEVATION: 5307.5 FT

Figure A.17 Logs of core Borings NCG 34 (Continued) and NCG 35.

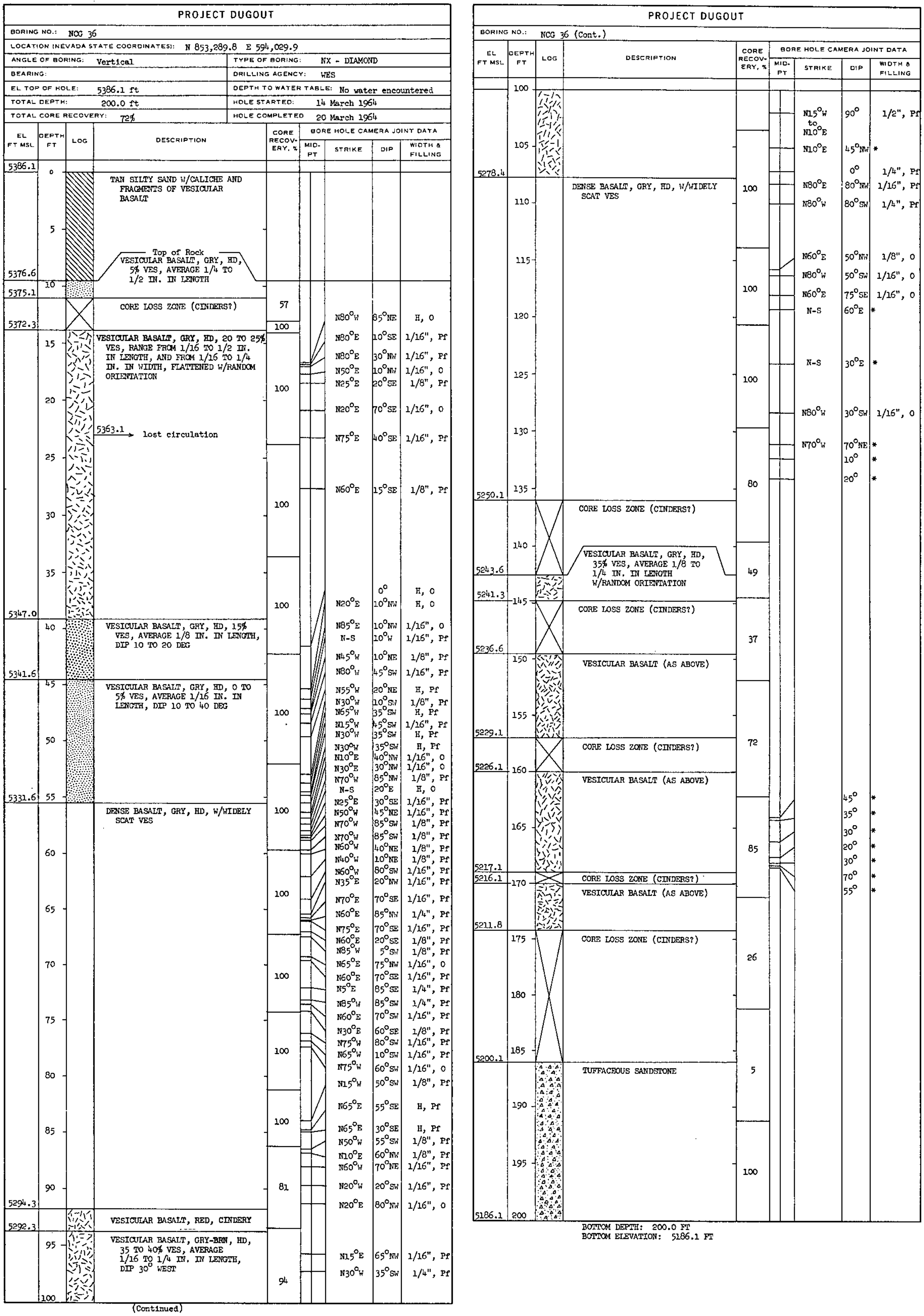
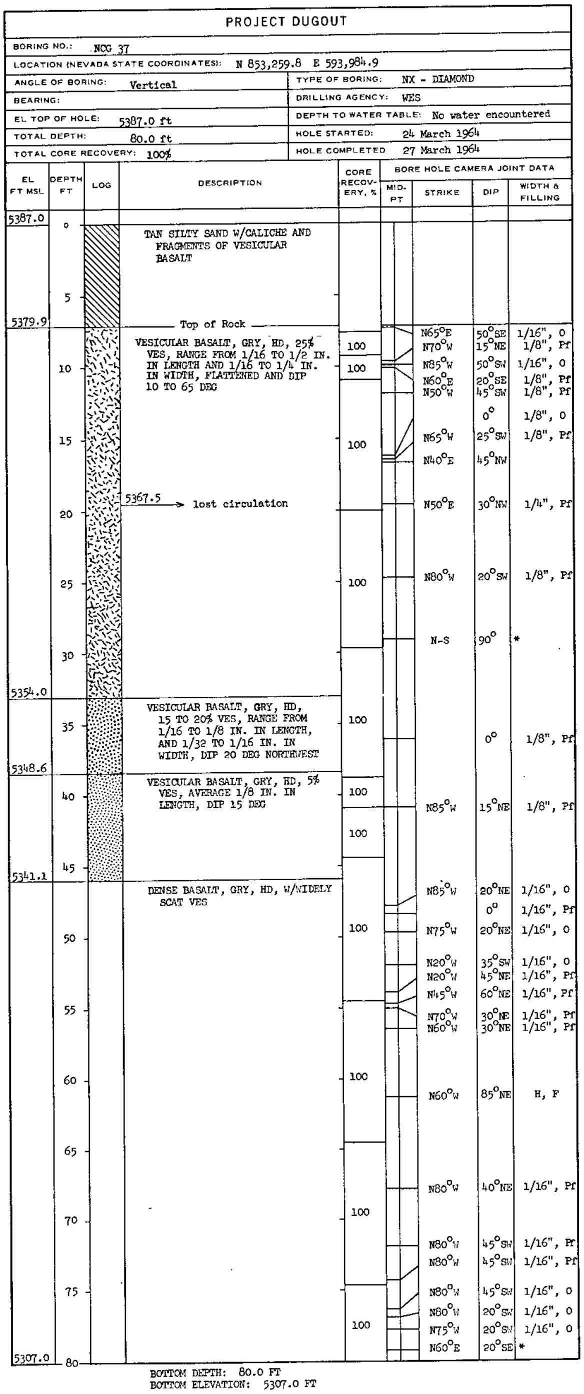


Figure A.18 Log of core Boring NCG 36.



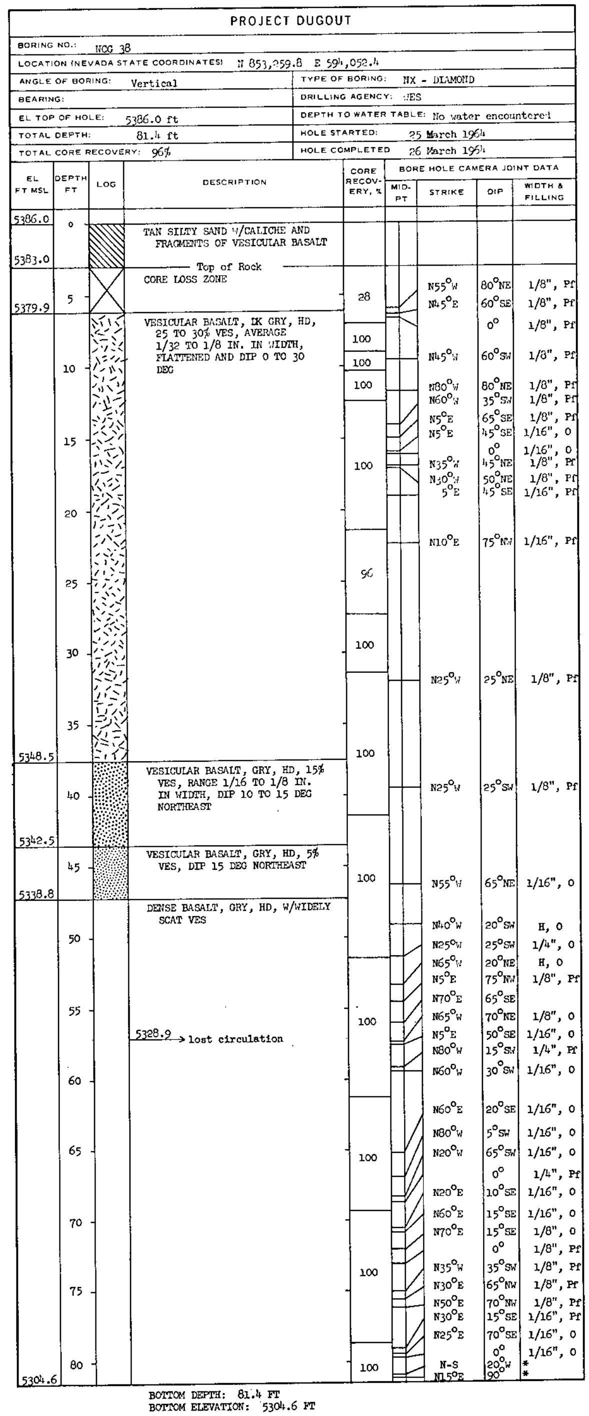
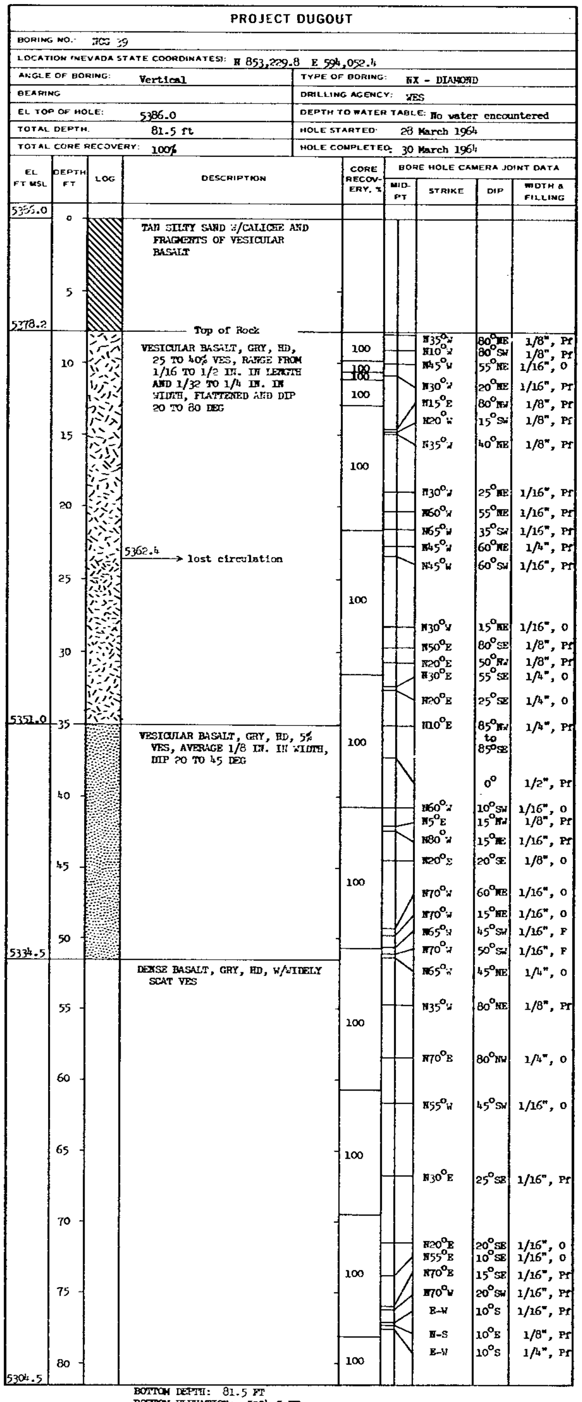


Figure A.19 Logs of core Borings NCG 37 and NCG 38.



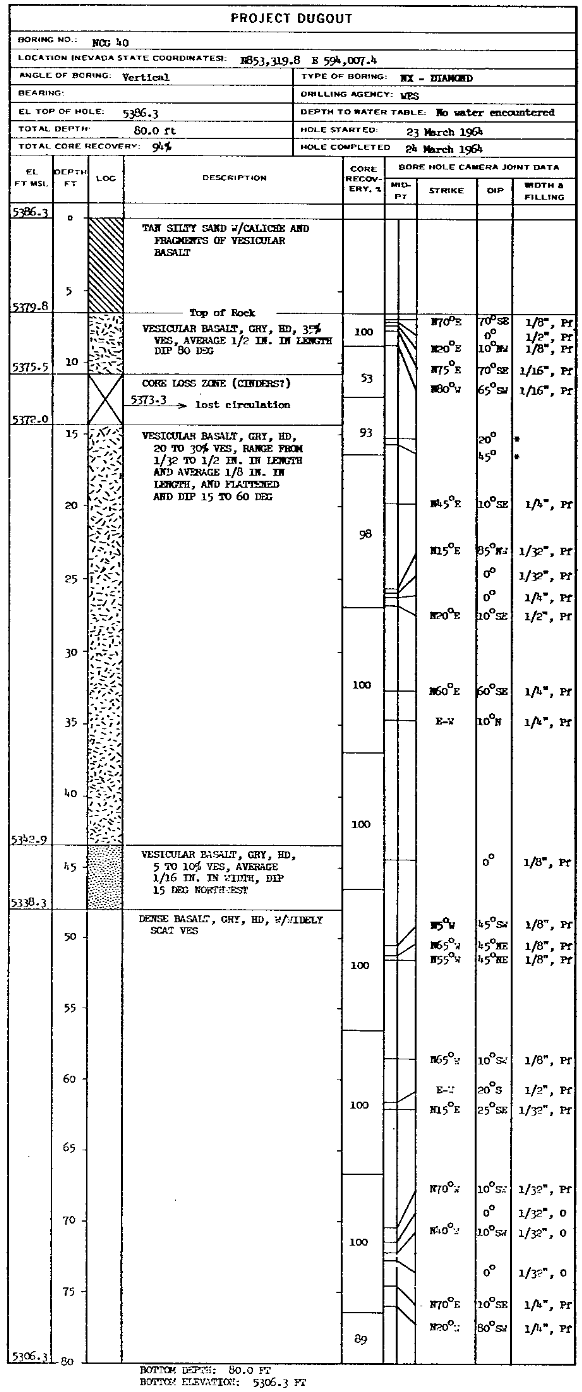
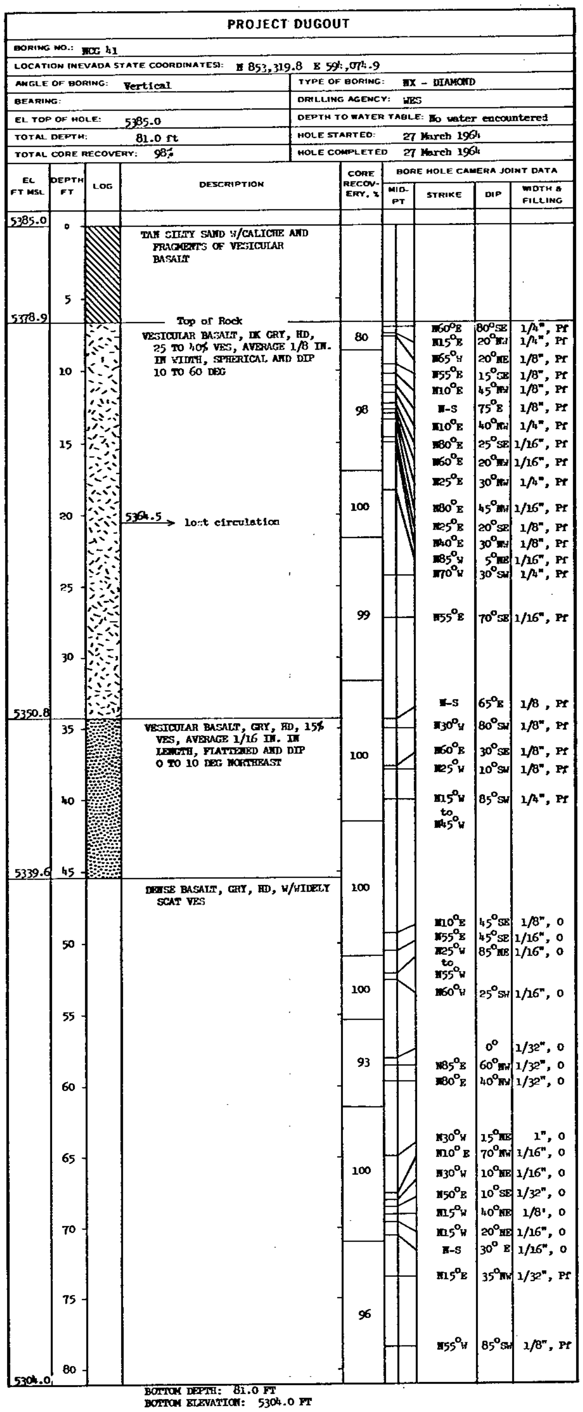


Figure A.20 Logs of core Borings NCG 39 and NCG 40.



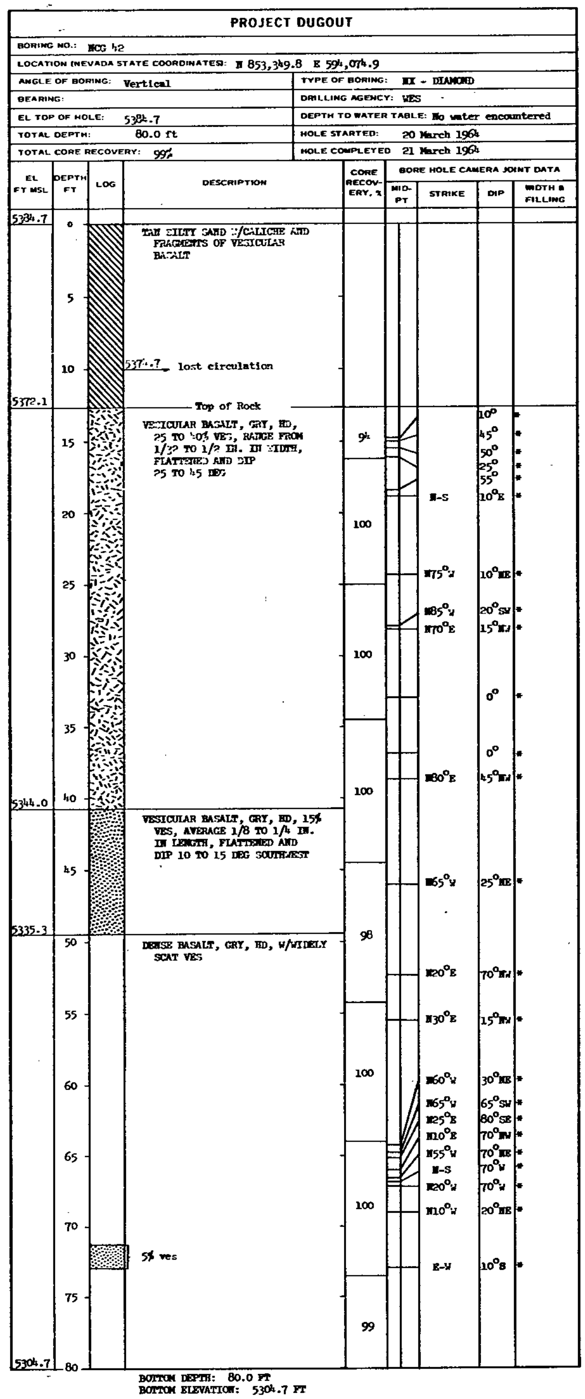


Figure A.21 Logs of core Borings NCG 41 and NCG 42.

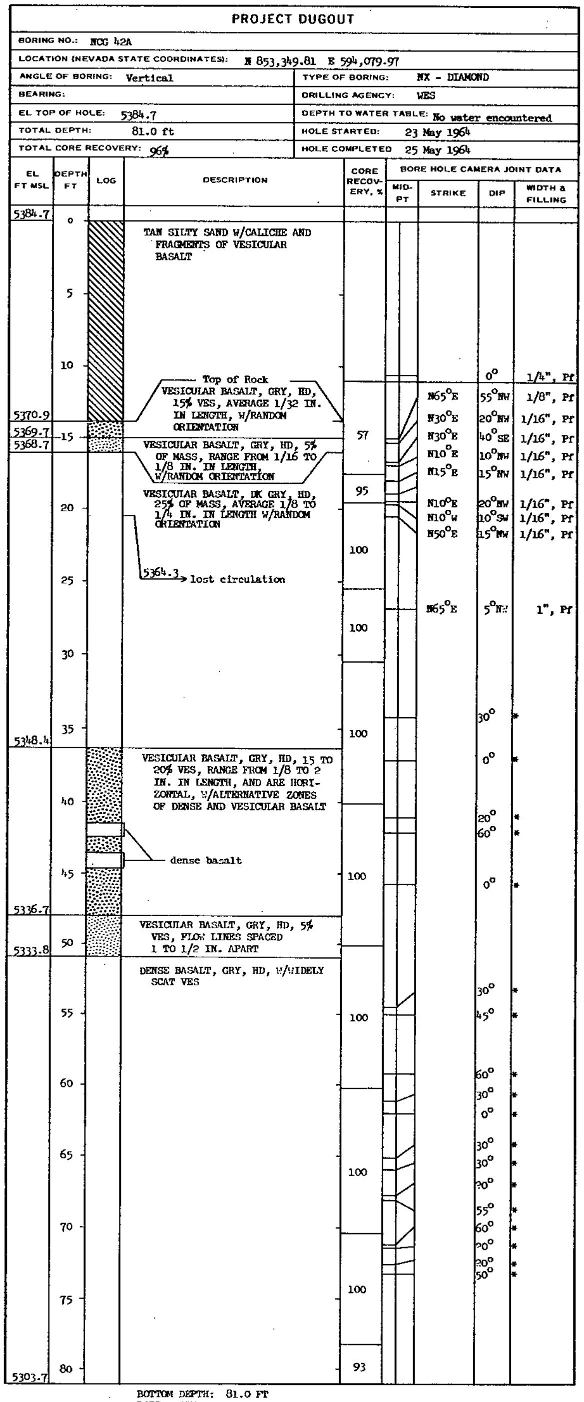


Figure A.22 Log of core Boring NCG 42A.

PROJECT DUGOUT

BORING NO.: NCG 43	
LOCATION (NEVADA STATE COORDINATES): N853,289.9 E 593,685.0	
ANGLE OF BORING: Vertical	TYPE OF BORING: NX - DIAMOND
BEARING:	DRILLING AGENCY: WES
EL TOP OF HOLE: 5389.5 ft	DEPTH TO WATER TABLE: No water encountered
TOTAL DEPTH: 120.0 ft	HOLE STARTED: 30 April 1964
TOTAL CORE RECOVERY: 97%	HOLE COMPLETED 2 May 1964

EL FT MSL	DEPTH FT	DESCRIPTION	CORE RECOVERY, %	STRIKE	DIP	WIDTH & FILLING
5390.0	0	TAN SILTY SAND W/CALICHE AND FRAGMENTS OF VESICULAR BASALT				
5387.7		Top of Rock				
		VESICULAR BASALT, DK GRY, HD, 20 TO 25% VES, AVERAGE 1/16 TO 1/4 IN. IN LENGTH, FLATTENED W/RANDOM ORIENTATION	100		0°	1/2", Pf
	5		100	N30°E	25°NW	1/8", Pf
			100	N45°E	5°SE	1/2", Pf
	10	5380.0 → lost circulation		N-S	10°E	1/2", Pf
				N70°W	20°SW	1/4", Pf
			100			
	15			N60°W	10°SW	1/16", Pf
				N45°E	10°NW	1/8", Pf
				N15°W	10°NE	1/8", Pf
				N75°W	35°SW	1/16", Pf
	20				0°	1/2", Pf
			100			
	25				0°	1/2", Pf
					0°	1/2", Pf
	30					
	35		100			
5353.2						
	40	VESICULAR BASALT, GRY, HD, 15% VES, AVERAGE 1/16 TO 1/4 IN. IN LENGTH, AND ARE HORIZ				
5347.8		VESICULAR BASALT, GRY, HD, 5 TO 10% VES, DIP 0 TO 10 DEG	99			
5345.0	45	DENSE BASALT, GRY, HD, W/WIDELY SCAT VES			0°	1/2", Pf
				N65°E	80°NW	1/4", Pf
				N65°E	30°NW	1/16", Pf
				N80°E	80°NW	1/8", Pf
	50					
			100	N65°E	65°SE	1/8", O
	55			N55°E	70°SE to 70°NW	1/4", Pf
				N60°E	75°SE	1/4", Pf
				N65°E	60°NW	1/16", Pf
	60		100			
				N-S to N60°E	80°E to 45°NW to 20°SE	1/8", O
	65					
			96			
		5% ves				
	70	5% ves			0°	1/16", O
				N85°W to N50°E	80°NE to 60°SE	1/4", Pf
		15% ves				
	75			N35°W	40°SW	1/16", Pf
		5% ves	88			
	80					
5308.6		CORE LOSS ZONE (CINDERS?)				
5305.7?	85	VESICULAR BASALT, BRN, HD, 25% VES, AVERAGE 1/8 TO 1/4 IN. IN LENGTH, W/RANDOM ORIENTATION	68			
	90				0°	1/2", Pf
			98	N-S to N35°E	80°E to 80°NW	1/4", Pf
	95			N25°W	35°NE	1/8", Pf
5393.0		VESICULAR BASALT, DK GRY, HD, 15% VES, AVERAGE 1/4 IN. IN LENGTH, AND ARE HORIZ		N10°W	45°NE	1/8", Pf
	100					

(Continued)

PROJECT DUGOUT

BORING NO.: NCG 43 (Cont.)

EL FT MSL	DEPTH FT	DESCRIPTION	CORE RECOVERY, %	STRIKE	DIP	WIDTH & FILLING
	100					
5289.2		VESICULAR BASALT, GRY, HD, 5% VES, 1/8 TO 1/4 IN. IN LENGTH	99			
5288.0		DENSE BASALT, GRY, HD, W/WIDELY SCAT VES				
	105			N10°W	5°SW	1/8", Pf
	110		100	N-S	80°E	1/4", F
	115				20°	*
			100			
5270.0	120					

BOTTOM DEPTH: 120.0 FT
BOTTOM ELEVATION: 5270.0 FT

Figure A.23 Log of core Boring NCG 43.

PROJECT DUGOUT

BORING NO.:	NCG 44
LOCATION (NEVADA STATE COORDINATES):	N 853,230.02 E 593,985.00
ANGLE OF BORING:	30 Degrees
TYPE OF BORING:	NX - DIAMOND
BEARING:	North
DRILLING AGENCY:	WES
EL TOP OF HOLE:	5386.9 ft
DEPTH TO WATER TABLE:	No water encountered
TOTAL DEPTH:	121.0 ft
HOLE STARTED:	18 March 1964
TOTAL CORE RECOVERY:	99%
HOLE COMPLETED:	20 March 1964

EL FT MSL	DEPTH FT	DESCRIPTION
5386.9	0	TAN SILTY SAND W/CALICHE AND FRAGMENTS OF VESICULAR BASALT
5378.4		Top of Rock
5378.4		VESICULAR BASALT, DK GRY, HD, 5 TO 10% VES, AVERAGE 1/8 IN. IN LENGTH, SPHERICAL
5377.1		VESICULAR BASALT, DK GRY, HD, 20 TO 30% VES, AVERAGE 1/8 IN. IN LENGTH, SPHERICAL
5375.8		VESICULAR BASALT, DK GRY, HD, 10 TO 15% VES, AVERAGE 1/8 TO 1/4 IN. IN LENGTH, AND ARE HORIZ
5372.5		VESICULAR BASALT, DK GRY, HD, 20 TO 30% VES, AVERAGE 1/8 TO 1/4 IN. IN LENGTH, W/RANDOM ORIENTATION
5367.6		lost circulation
5356.4	35	VESICULAR BASALT, GRY-BRN, 10 TO 20% VES, AVERAGE 1/8 TO 1/4 IN. IN LENGTH, ELLIPSOIDAL
5352.3	40	DENSE BASALT, GRY, HD, W/SCAT VES
5351.4		
5350.7		VESICULAR BASALT, GRY-BRN, HD, 10 TO 20% VES
5349.5		DENSE BASALT, GRY, HD, W/SCAT VES
5348.7		VESICULAR BASALT, GRY-BRN, HD, 10 TO 20% VES
		DENSE BASALT, GRY, HD, W/WIDELY SCAT VES

Core recovery, %: 97, 100, 100, 100, 100, 100, 100, 100, 100, 99, 100

BORE HOLE CAMERA JOINT DATA

STRIKE	DIP	WIDTH & FILLING
	80°	*
	60°	*
N40°E	55°SE	1/4", O
N16°E	34°NW	1/4", O
N50°W	29°SW	1/16", O
N82°E	21°SE	1/16", O
N73°E	10°SE	1/16", Pf
E-W	80°S	1/2", Pf
N50°W	16°S	1/16", O
N05°W	24°NE	1/16", O
N66°W	26°NE	1/16", Pf
N27°E	53°SE	1/16", Pf
N01°E	42°NW	1/16", O
N84°E	10°SE	1/16", Pf
N62°E	12°SE	1/16", Pf
N62°E	12°SE	1/16", Pf
N04°E	17°SE	1/16", Pf
N80°W	15°NE	1/4", Pf
N64°W	16°NE	1/16", Pf
N80°W	15°NE	1/4", Pf
N80°W	20°NE	1/16", O
N82°E	10°SE	1/16", O
N80°W	15°NE	1/16", O
N81°E	76°NW	1/16", O
N31°W	85°NE	1/16", O
N62°W	12°NE	1/8", Pf
N62°W	12°NE	1/4", Pf
N72°W	16°NE	1/16", Pf
N43°W	13°NE	1/4", Pf
N56°W	22°NE	1/8", Pf
N52°W	28°NE	1/16", Pf
E-W	10°N	1/16", Pf
N48°W	08°NE	1/4", O
N84°E	30°NW	1/8", O
N47°W	31°NE	1/16", Pf
N47°W	43°NE	1/16", Pf
N18°W	52°NE	1/16", Pf
N48°W	82°SW	1/16", O
N74°W	51°NE	H, F
N80°W	21°SW	H, F
N51°W	82°NE	1/16", O
N58°W	69°SW	1/16", O
N84°E	50°NW	1/16", O
N33°E	56°SE	1/8", Pf
N52°W	83°SW	1/16", Pf
N58°W	69°SW	1/8", O
N85°W	34°SW	H, F
N61°W	70°SW	1/16", O
N41°W	60°SW	1/16", O
N26°W	52°SW	1/16", O
N70°W	46°SW	1/16", O
N13°W	28°NE	1/16", Pf
N45°W	45°SW	1/16", Pf
N56°W	80°NE	1/4", Pf
N21°W	66°NE	1/16", Pf
N49°W	40°SW	1/16", Pf
N70°W	24°SW	1/16", Pf
N51°W	34°SW	1/16", Pf
N39°E	54°NW	1/16", O
	60°	*
	30°	*

(Continued)

PROJECT DUGOUT

BORING NO.: NCG 44 (Cont.)

EL FT MSL	DEPTH FT	CORE RECOVERY, %	DIP	WIDTH & FILLING
	100	100		
	105	99	60°	*
			30°	*
	110			
	115	100	30°	*
			30°	*
			30°	*
5282.1	120		60°	*

BOTTOM DEPTH: 121.0 FT
BOTTOM ELEVATION: 5282.1 FT

Note: Depths shown represent slant distances

Figure A.24 Log of core Boring NCG 44.

PROJECT DUGOUT

BORING NO.:	NCG 45		
LOCATION (NEVADA STATE COORDINATES):	N 853, 230.00 E 993,980.00		
ANGLE OF BORING:	30 Degrees	TYPE OF BORING:	NX - DIAMOND
BEARING:	West	DRILLING AGENCY:	WES
EL TOP OF HOLE:	5386.9 ft	DEPTH TO WATER TABLE:	No water encountered
TOTAL DEPTH:	120.3 ft	HOLE STARTED:	21 May 1964
TOTAL CORE RECOVERY:	99%	HOLE COMPLETED:	22 May 1964

EL FT MSL	DEPTH FT	DESCRIPTION
5386.9	0	TAN SILTY SAND W/CALICHE AND FRAGMENTS OF VESICULAR BASALT
5378.2	10	Top of Rock. VESICULAR BASALT, DK GRY, HD, 5% VES, AVERAGE 1/32 IN. IN WIDTH, SPHERICAL W/RANDOM ORIENTATION
5373.2	15	VESICULAR BASALT, GRY-BRN, HD, 25 TO 30% VES, AVERAGE 1/16 IN. IN WIDTH AND 1/4 IN. IN LENGTH W/RANDOM ORIENTATION; 5369.9 → lost circulation
5362.4		VESICULAR BASALT, GRY-BRN, HD, 10 TO 15% VES, AVERAGE 1/16 TO 1/4 IN. IN LENGTH, DIP 35 DEG
5361.0	30	VESICULAR BASALT, GRY, HD, 20 TO 25% VES, AVERAGE 1/16 TO 1/4 IN. IN LENGTH, ELLIPSOIDAL
5356.6		VESICULAR BASALT, GRY-BRN, HD, 10 TO 15% VES, AVERAGE 1/16 TO 1/4 IN. IN LENGTH
5355.9	35	VESICULAR BASALT, GRY, HD, 25 TO 30% VES, RANGE 1/16 TO 1/2 IN. IN LENGTH W/RANDOM ORIENTATION
5347.2	45	VESICULAR BASALT, DK GRY, HD, 10 TO 15% VES, RANGE FROM 1/16 TO 1/4 IN. IN LENGTH
5345.1		DENSE BASALT, GRY, HD, W/WIDELY SCAT VES
	~58	5% ves
5266.6	120	

CORE RECOVERY, % (top to bottom): 83, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100 (Cont.: 100, 100)

BORE HOLE CAMERA JOINT DATA

STRIKE	DIP	WIDTH & FILLING
N64°E	59°SE	1/8", O
N35°E	88°SE	1/16", O
N10°W	65°SW	1/4", O
N54°E	20°NW	1/16", O
N54°W	26°NE	1/16", O
N04°W	25°NE	1", Pf
N08°W	21°NE	1/8", Pf
N34°W	14°NE	1/2", Pf
N55°E	20°NW	1/4", O
N22°W	88°NE	1/8", Pf
N04°E	25°SE	1/8", Pf
N18°W	17°NE	1/32", O
N19°W	10°NE	1/16", O
N24°W	18°NE	1/16", O
N86°E	58°SE	1/16", O
N57°E	15°NW	1/16", O
N64°E	24°NW	1/16", O
N32°W	69°SW	1/16", O
N31°W	13°NE	1/16", O
N47°W	26°SW	1/16", O
N20°W	21°NE	1/16", O
N68°W	67°SW	1/16", O
N10°W	10°NE	1/16", O
N86°E	07°NW	1/16", O
N30°W	06°NE	1/16", O
N46°W	19°SW	1/16", O
N26°W	87°NE	1/8", Pf
N76°W	09°NE	1/8", Pf
N60°E	80°NW	1/8", Pf
N43°E	14°NW	1/8", Pf
	0°	1/16", O
N74°E	82°SE	1/4", Pf
N81°E	84°SE	1/4", Pf
N10°E	30°SE	1/4", Pf
N82°W	74°SW	1/4", Pf
N21°W	40°NE	1/16", Pf
N72°W	20°SW	1/16", Pf
N78°W	22°SW	1/16", O
N78°E	16°SE	1/16", O
N32°W	22°SW	1/16", O
N72°E	23°SE	1/16", Pf
N78°E	16°SE	1/16", Pf
N40°E	16°SE	1/16", Pf
N28°W	12°SW	1/2", Pf
N14°E	15°NW	1/16", Pf
N36°E	68°SE	1/2", Pf

(Continued)

PROJECT DUGOUT

BORING NO.: NCG 45 (Cont.)

STRIKE	DIP	WIDTH & FILLING
N89°W	72°SW	1/4", Pf
N40°E	33°SE	1/16", Pf
N15°E	55°NW	1/4", Pf
N40°E	16°SE	1/16", Pf
N80°E	50°NW	1/8", Pf
N75°W	74°NE	1/16", Pf
N32°E	40°SE	1/2", Pf
N82°W	74°SW	1/2", Pf
N14°E	74°SE	1/4", O
N63°W	24°SW	1/16", O
N11°E	70°NW	1/16", O
N61°E	14°SE	1/16", O
N09°E	15°SE	1/16", O
	80°	*

BOTTOM DEPTH: 120.3 FT
BOTTOM ELEVATION: 5266.6 FT

Note: Depths shown represent slant distances

Figure A.25 Log of core Boring NCG 45.

APPENDIX B

PRESHOT AND POSTSHOT LOGS OF CALYX HOLES

LEGEND FOR CALYX HOLE LOGS

LITHOLOGY

SILTY SAND WITH FRAGMENTS OF BASALT

VESICULAR BASALT; 10 TO 20% VESICLES

CINDERS AND SCORIA

VESICULAR BASALT; 2 TO 10% VESICLES

VESICULAR BASALT; 20% VESICLES OR MORE

DENSE BASALT; < 2% VESICLES

LITHOLOGIC CONTACTS

SCHEMATIC REPRESENTATION OF ATTITUDE OF VESICLES AND LAYERS OF VESICLES

LARGE OPEN VESICLE OR CAVITY (TO SCALE)

PRESHOT JOINTS

WIDTH $\leqq$ 1/32"

1/32" < WIDTH $\leqq$ 1/8"

1/8" < WIDTH $\leqq$ 1/4"

1/4" < WIDTH $\leqq$ 1/2"

1/2" < WIDTH (TO SCALE)

WIDE, FILLED JOINT OR CAVITY (FILLING MATERIAL AS INDICATED)

POSTSHOT FRACTURE CONDITIONS

(HOLES U 18 M, U 18 N, U 18 O, AND U 18 P ONLY)

WIDTH $\leqq$ 1/32"

1/32" < WIDTH $\leqq$ 1/8"

1/8" < WIDTH $\leqq$ 1/4"

1/4" < WIDTH $\leqq$ 1/2"

1/2" < WIDTH

CAVITY; COMMONLY LOCALIZED ALONG FRACTURE WHERE EDGES TEND TO SPALL

1/8" O — RELATIVE DISPLACEMENT ALONG A FRACTURE IN DIRECTION NORMAL TO CALYX HOLE WALL; AMOUNT OF OFFSET INDICATED ON SIDE OF FRACTURE DISPLACED OUTWARD (O) INTO CALYX HOLE

OV — RELATIVE DISPLACEMENT ALONG A FRACTURE IN DIRECTION OBLIQUE TO CALYX HOLE WALL; SYMBOL OV ON SIDE DISPLACED OVER OPPOSITE SIDE

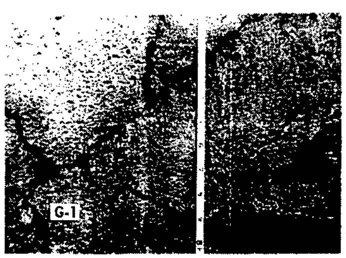
1/2" — RELATIVE DISPLACEMENT ALONG A FRACTURE IN DIRECTION PARALLELING CALYX HOLE WALL; ARROW AND MAGNITUDE INDICATE MOVEMENT WITH RESPECT TO OPPOSITE SIDE OF FRACTURE

$\frac{2.1}{2.0}$ — RELATIVE DISPLACEMENT OF MARKS ON OPPOSITE SIDES OF PRESHOT JOINT; POSTSHOT DISTANCE (INCHES) SHOWN OVER PRESHOT DISTANCE

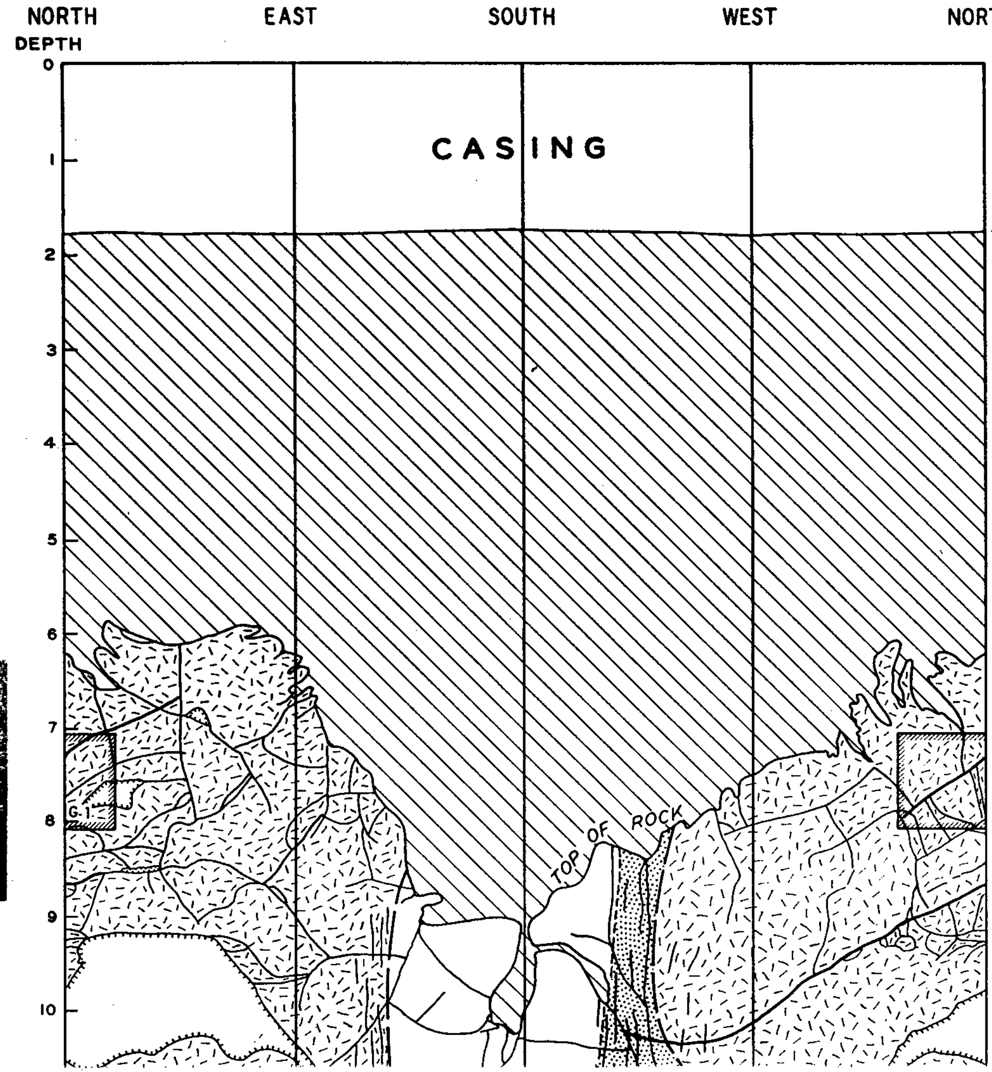
LOG OF CALYX HOLE

PROJECT: DUGOUT	HOLE NO.: U18G
ELEVATION: 5384.74	LOCATION: N853,289.90 E594,120.20
TOTAL DEPTH: 65.2 FT	HOLE DIAMETER: 36 IN.

PHOTOGRAPH



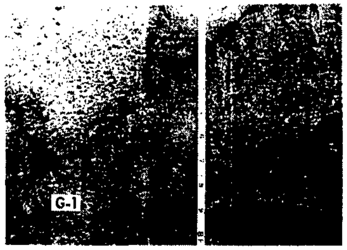
SECTION

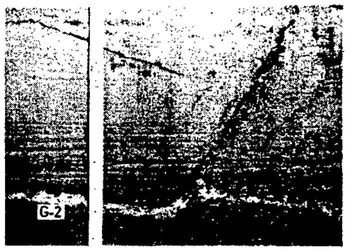


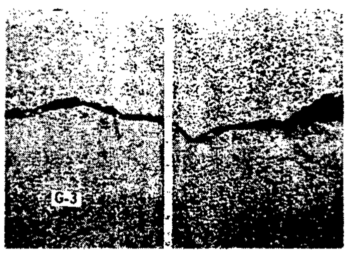
REMARKS

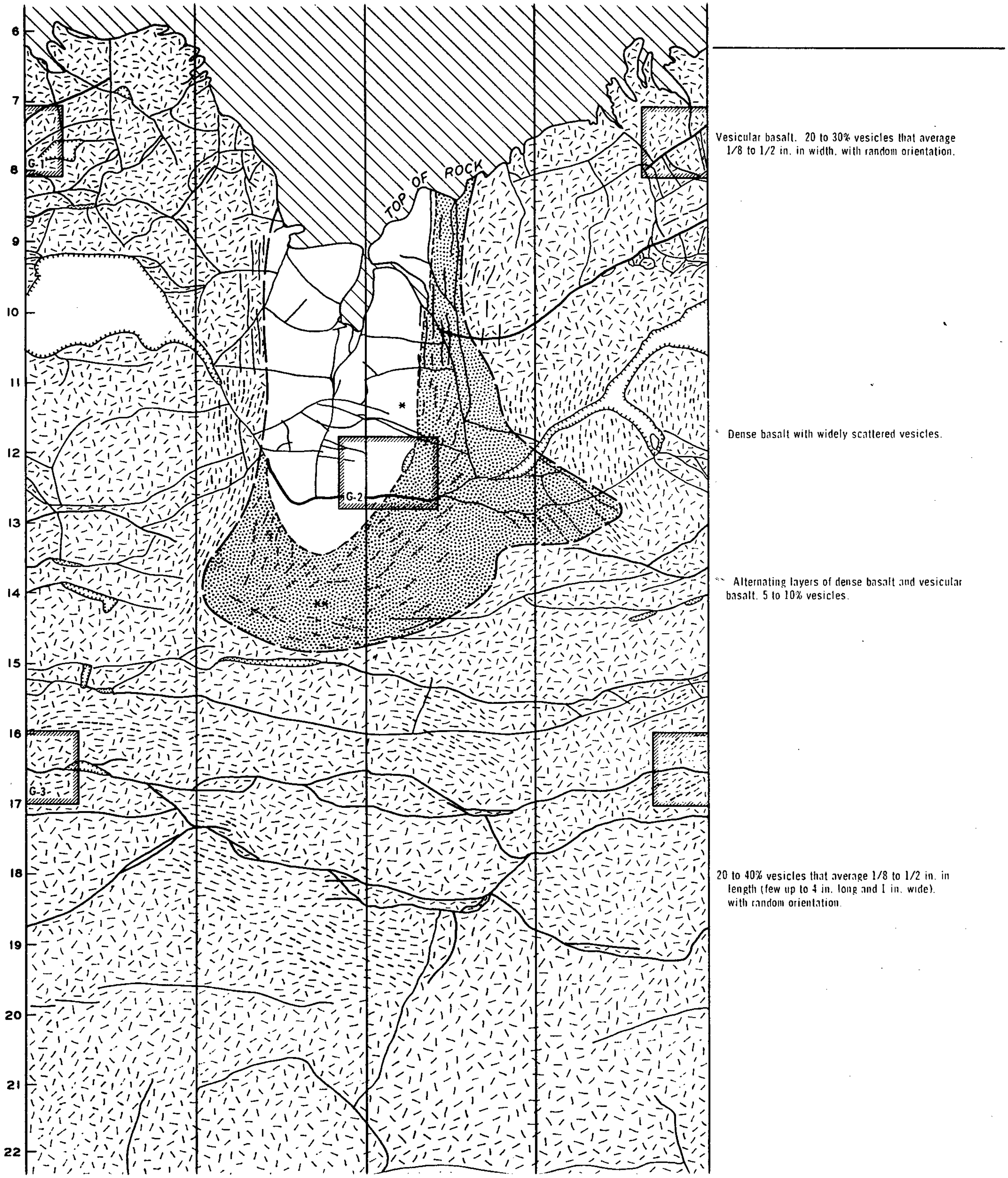
Tan, silty sand with caliche and fragments and boulders of vesicular basalt.

Vesicular basalt. 20 to 30% vesicles that average 1/8 to 1/2 in. in width, with random orientation.


G-1


G-2


G-3


6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
TOP OF ROCK
G-1
G-2
G-3
Vesicular basalt. 20 to 30% vesicles that average 1/8 to 1/2 in. in width, with random orientation.
Dense basalt with widely scattered vesicles.
Alternating layers of dense basalt and vesicular basalt. 5 to 10% vesicles.
20 to 40% vesicles that average 1/8 to 1/2 in. in length (few up to 4 in. long and 1 in. wide), with random orientation.

2

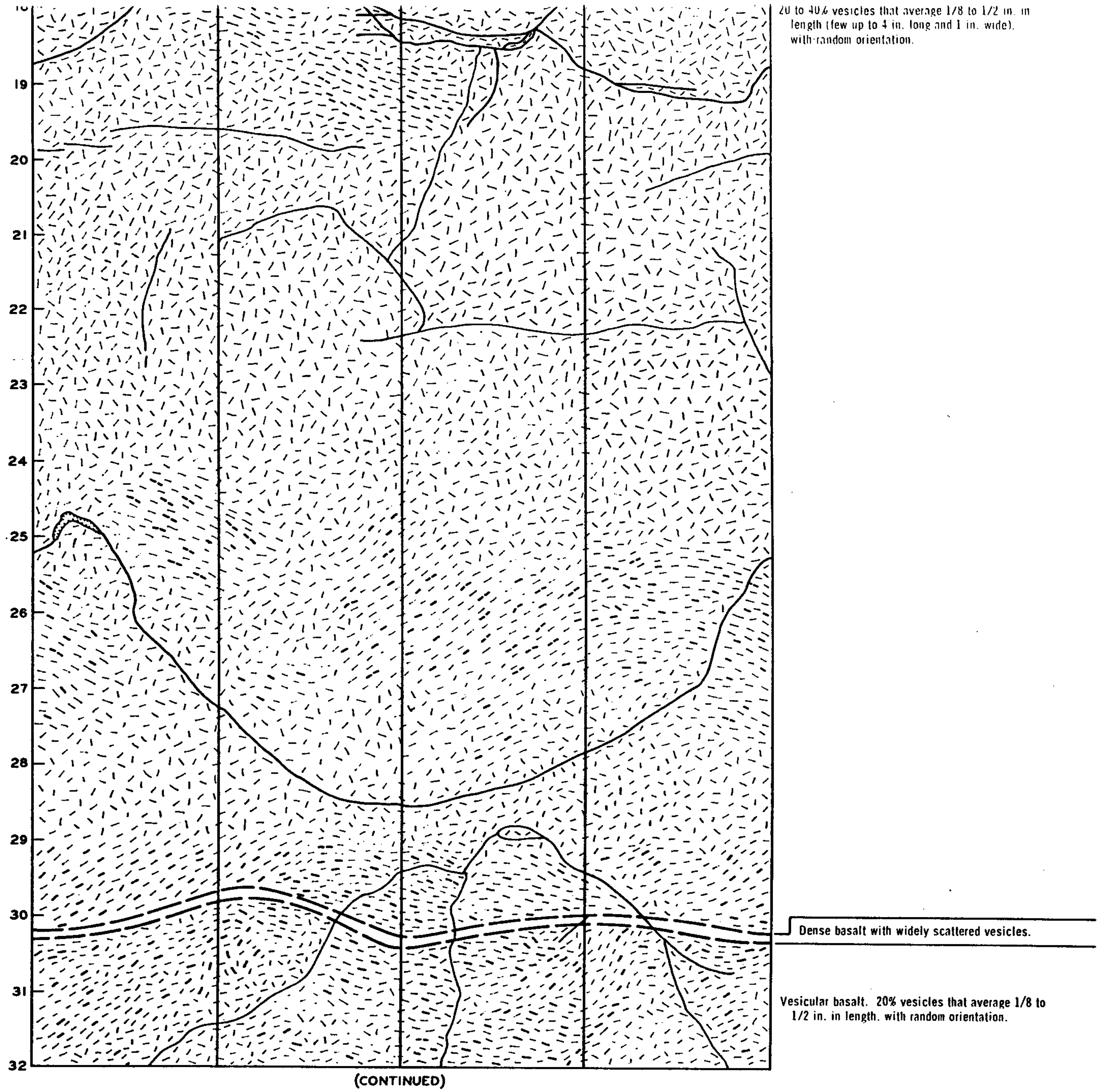


Figure B.1 Log of calyx Hole U18G.

3

(CONTINUED)

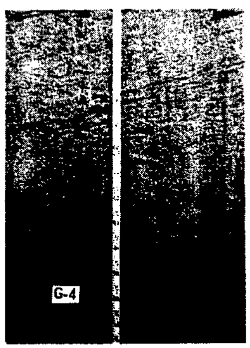
LOG OF CALYX HOLE

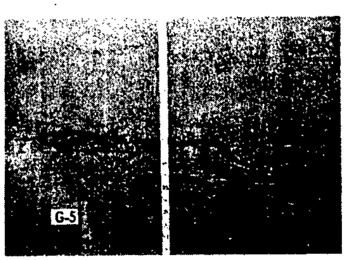
PROJECT: DUGOUT | HOLE NO.: U18G

ELEVATION: 5384.74 | LOCATION: N853,289.90 E594,120.20

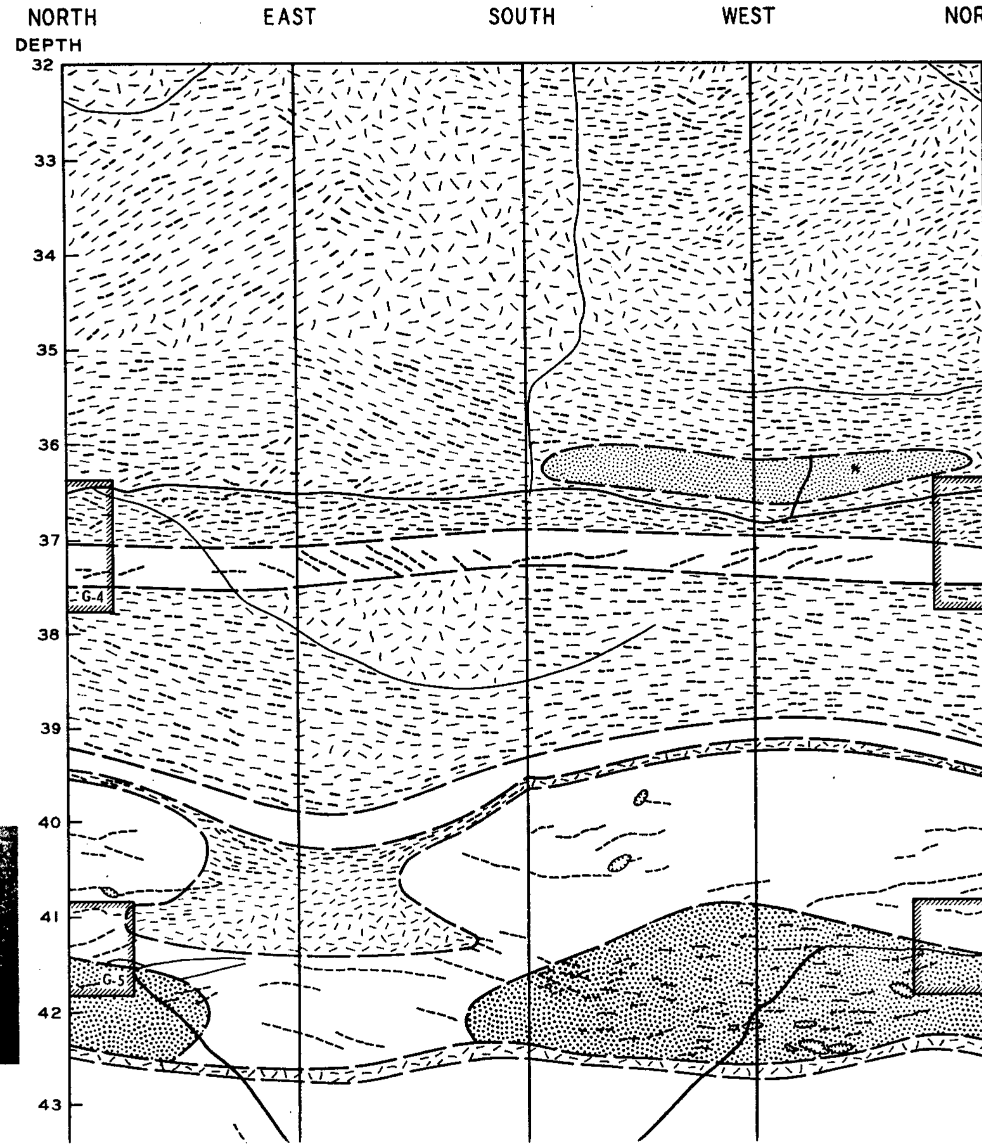
TOTAL DEPTH: 65.2 FT | HOLE DIAMETER: 36 IN.

PHOTOGRAPH





SECTION



REMARKS

* Vesicular basalt. 5 to 10% vesicles that average 1/2 in. in length and 1/8 in. in width, with random orientation.

Dense basalt with widely scattered vesicles.

Vesicular basalt. 35% vesicles that average 1/8 to 1/2 in. in length, with random orientation.

Dense basalt with widely scattered vesicles.

Vesicular basalt. 25% vesicles, part of flow fold.

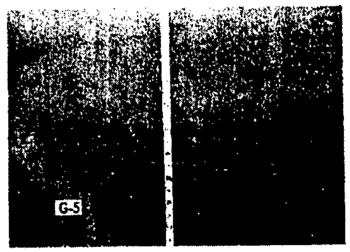
Dense basalt with widely scattered vesicles.

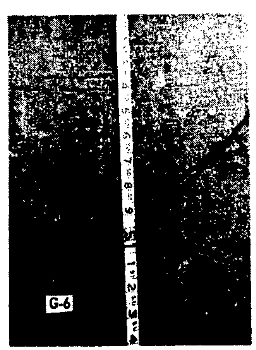
Vesicular basalt. 15% vesicles that average 1/16 to 1/2 in. in length, with random orientation.

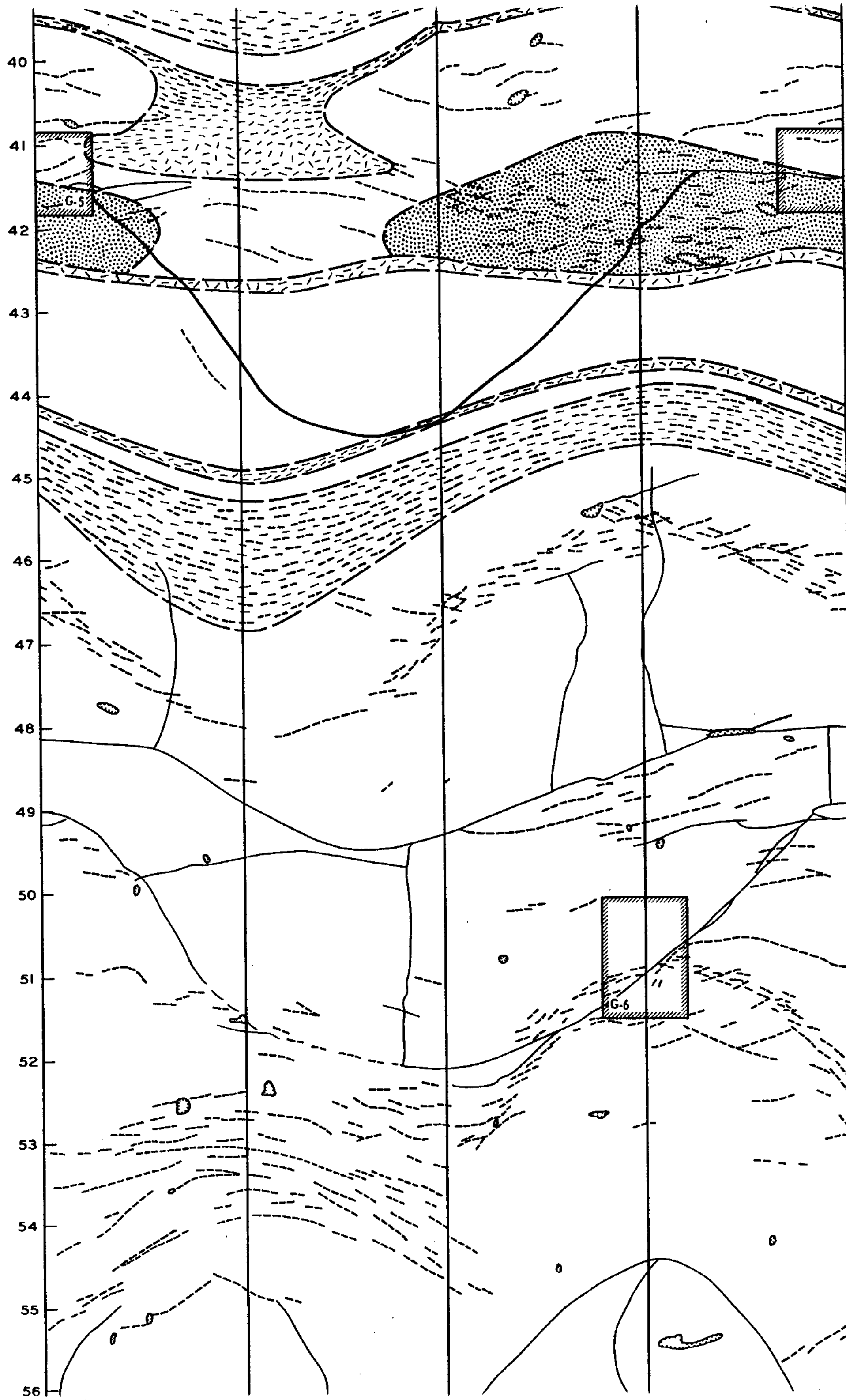
Vesicular basalt. 20% vesicles that average 1/4 in. in length and are horizontal.

Dense basalt with widely scattered vesicles.

1







Vesicular basalt. 25% vesicles, part of flow fold.

Dense basalt with widely scattered vesicles.

Vesicular basalt. 15% vesicles that average 1/16 to 1/2 in. in length, with random orientation.

Vesicular basalt. 20% vesicles that average 1/4 in. in length and are horizontal.

Dense basalt with widely scattered vesicles.

Vesicular basalt. 30% vesicles that average 1/2 in. in length and are horizontal.

Dense basalt with widely scattered vesicles.

Vesicular basalt. 30% vesicles that average 1/2 in. in length, dipping southeast.

Dense basalt with widely scattered vesicles dipping southeast.

2

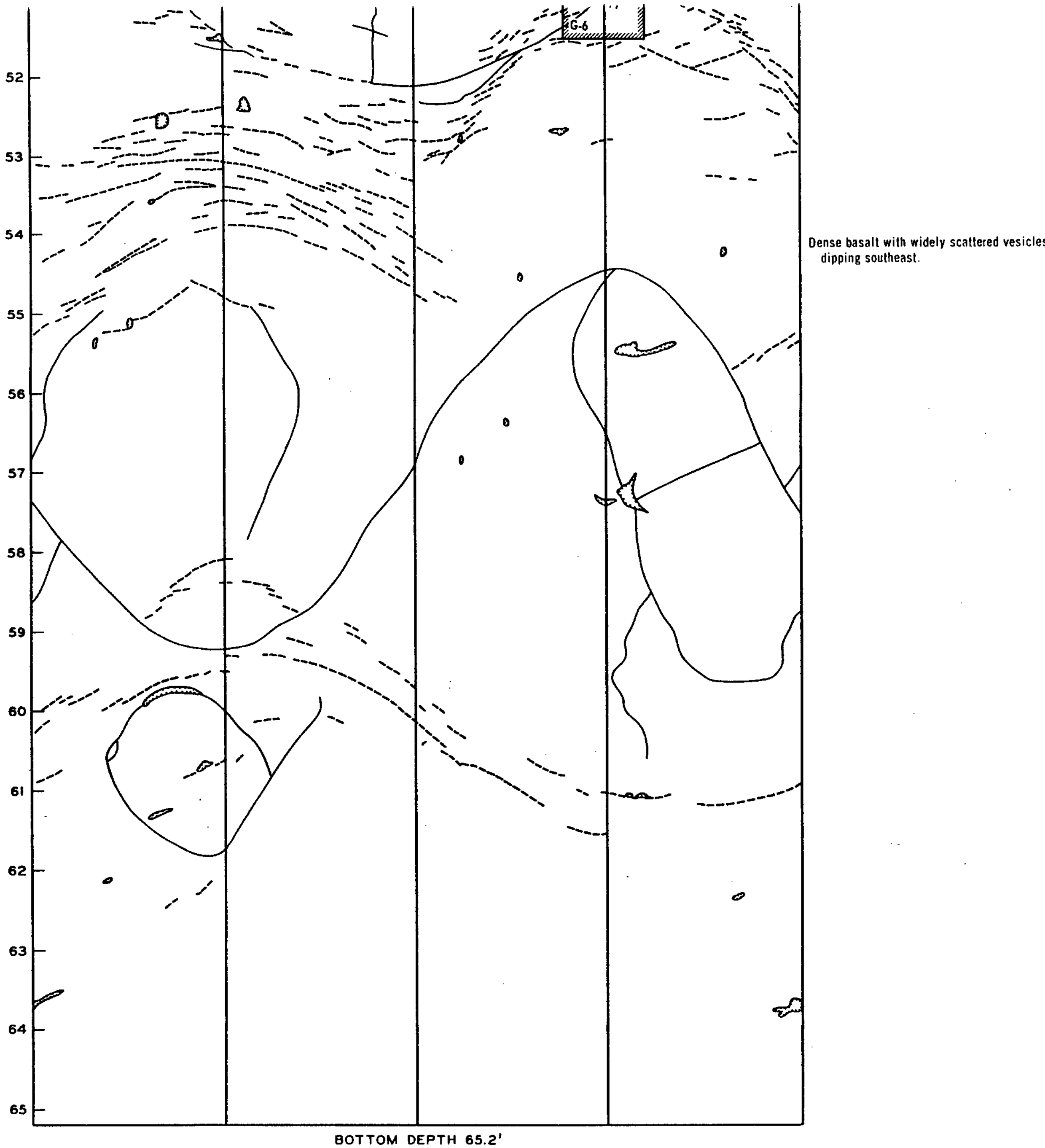


Figure B.2 Log of calyx Hole U18G (Continued).

3

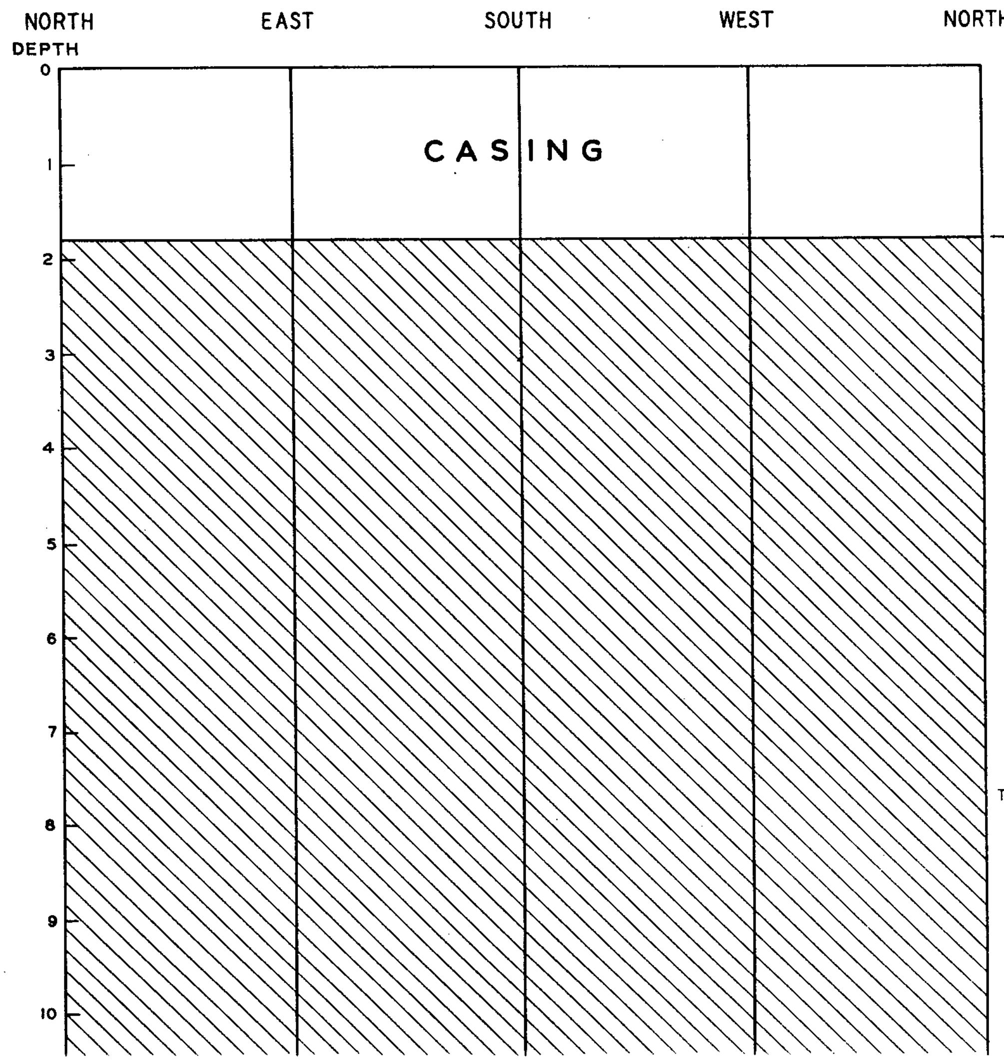
LOG OF CALYX HOLE

PROJECT: DUGOUT	HOLE NO.: U18H
ELEVATION: 5385.59	LOCATION: N853,290.00 E594,075.00
TOTAL DEPTH: 65.2 FT	HOLE DIAMETER: 36 IN.

PHOTOGRAPH

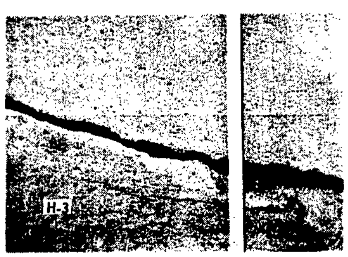
SECTION

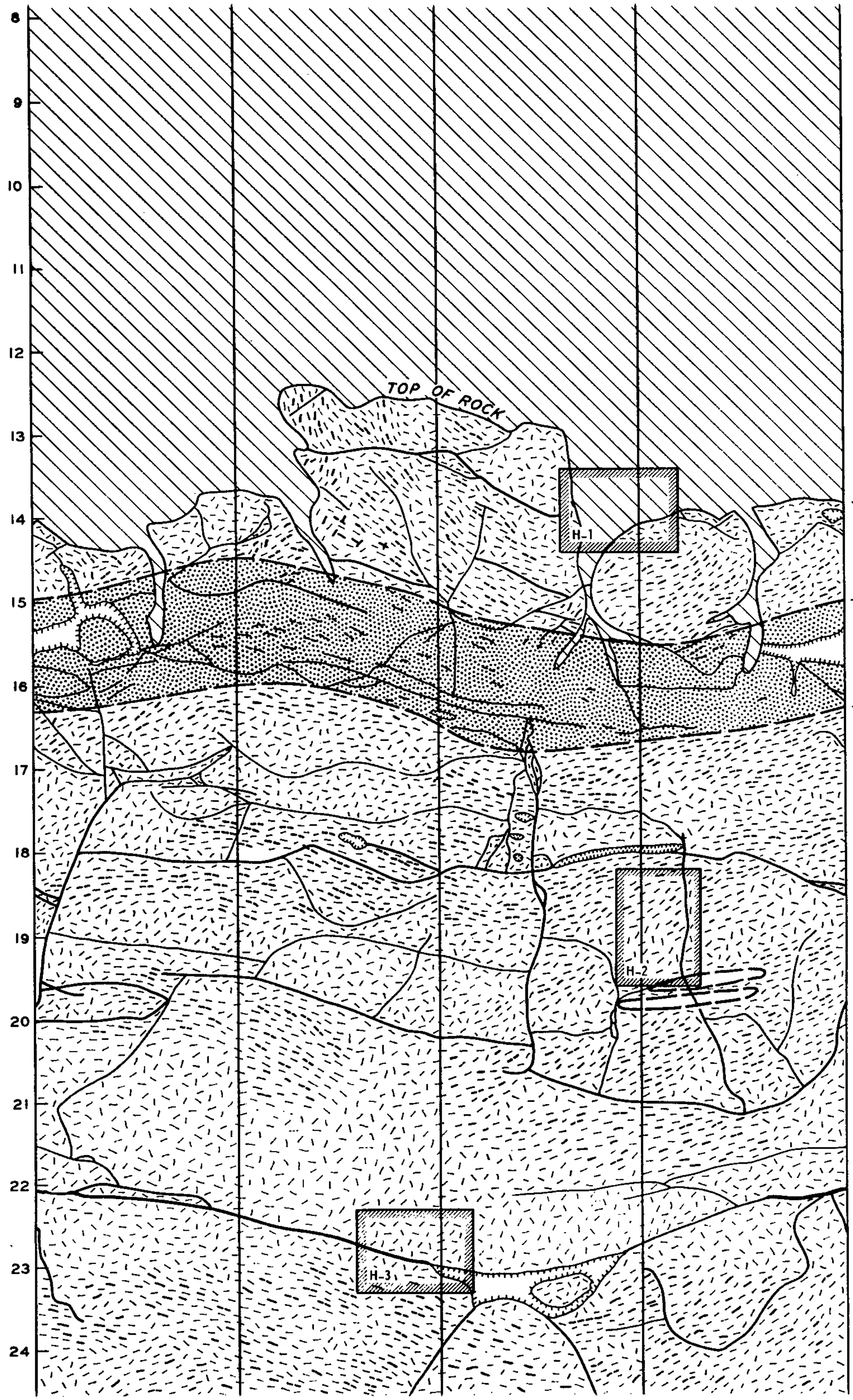
REMARKS



Tan, silty sand with caliche and fragments and boulders of vesicular basalt.

1





boulders of vesicular basalt.

Vesicular basalt. 20% vesicles that average 1/8 to 1/4 in. in length, with random orientation.

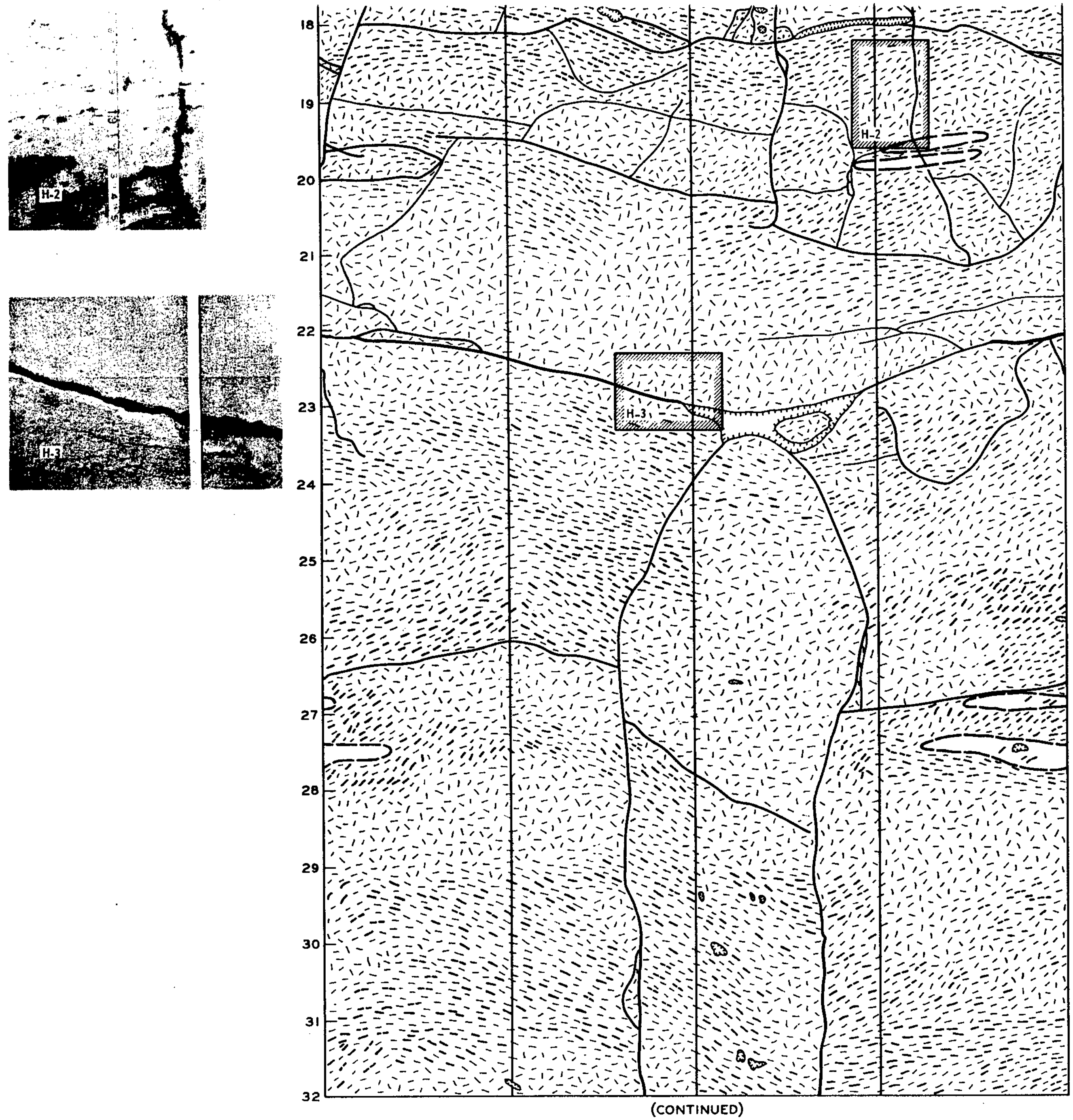
Vesicular basalt. 10% vesicles that range up to 1 in. in length, with random orientation.

Vesicular basalt. 20% vesicles that range up to 1 in. in length and average 1/8 to 1/4 in. in length dipping south.

20% vesicles, that average 1/4 in. in length, with random orientation.

25% vesicles, with two size ranges: smaller size that averages 1/8 to 1/4 in. in length, 20% of the vesicles; larger size up to 2 in. in length, and

(2)



with random orientation.

25% vesicles, with two size ranges: smaller size that averages 1/8 to 1/4 in. in length, 20% of the vesicles; larger size up to 2 in. in length, and 1/4 in. in width, 5% of the vesicles. Vesicles are horizontal or dipping 10 to 15 degrees southwest.

Figure B.3 Log of calyx Hole U18H.

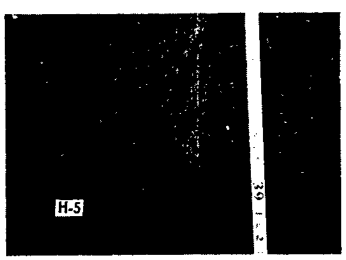
3

(CONTINUED)

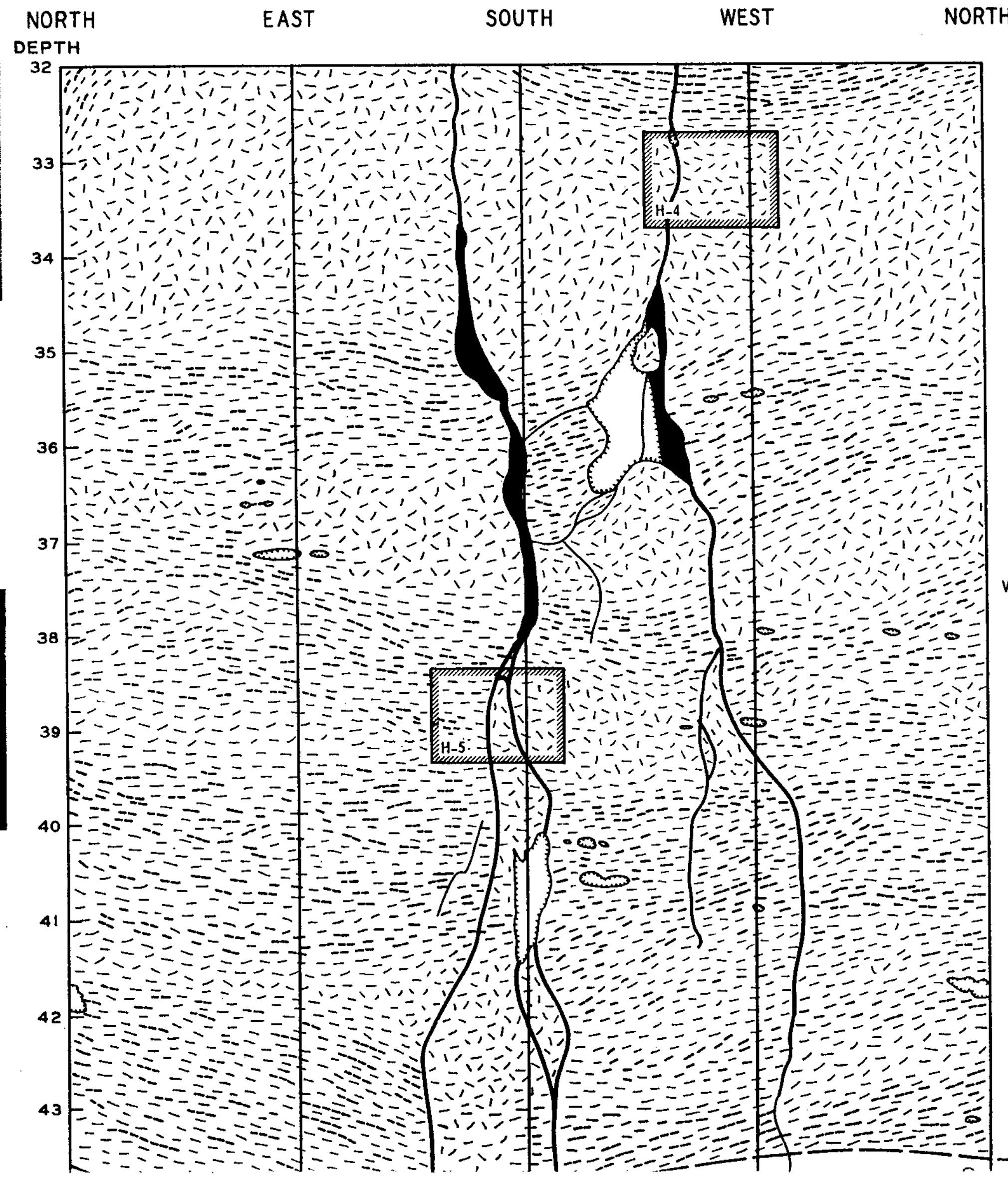
LOG OF CALYX HOLE

PROJECT: DUGOUT	HOLE NO.: U18H
ELEVATION: 5385.59	LOCATION: N853,290.00 E594,075.00
TOTAL DEPTH: 65.2 FT	HOLE DIAMETER: 36 IN.

PHOTOGRAPH



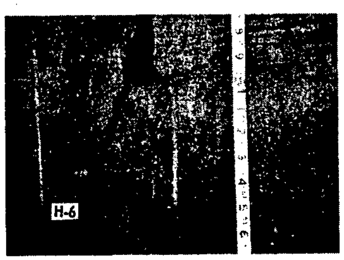
SECTION

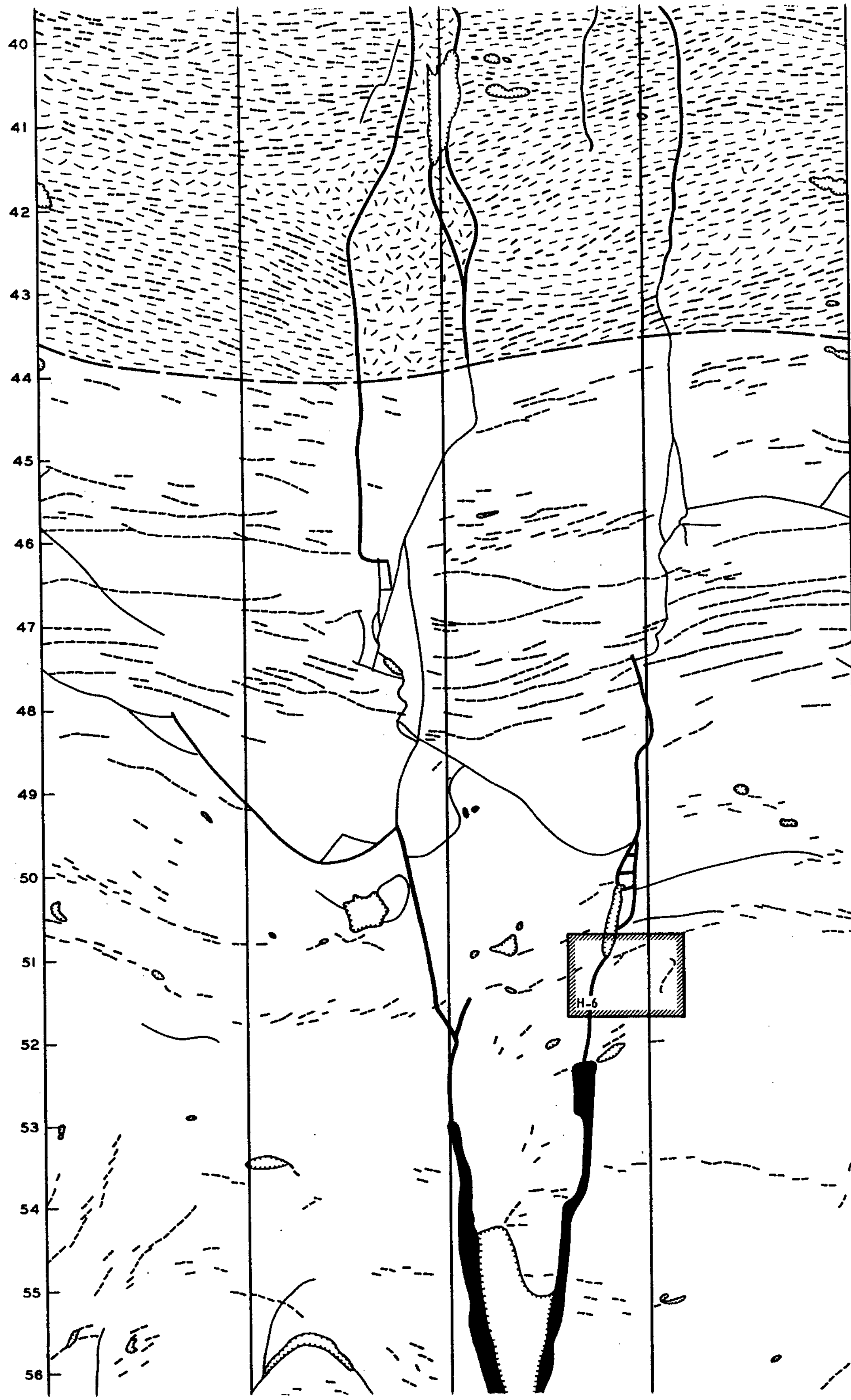


REMARKS

Vesicular basalt. 15 to 30% vesicles that range from 1/4 to 6 in. in length, and 1/8 to 1 in. in width, with lenses and layers of dense basalt, and are horizontal.

①





Dense basalt with widely scattered vesicles.

2

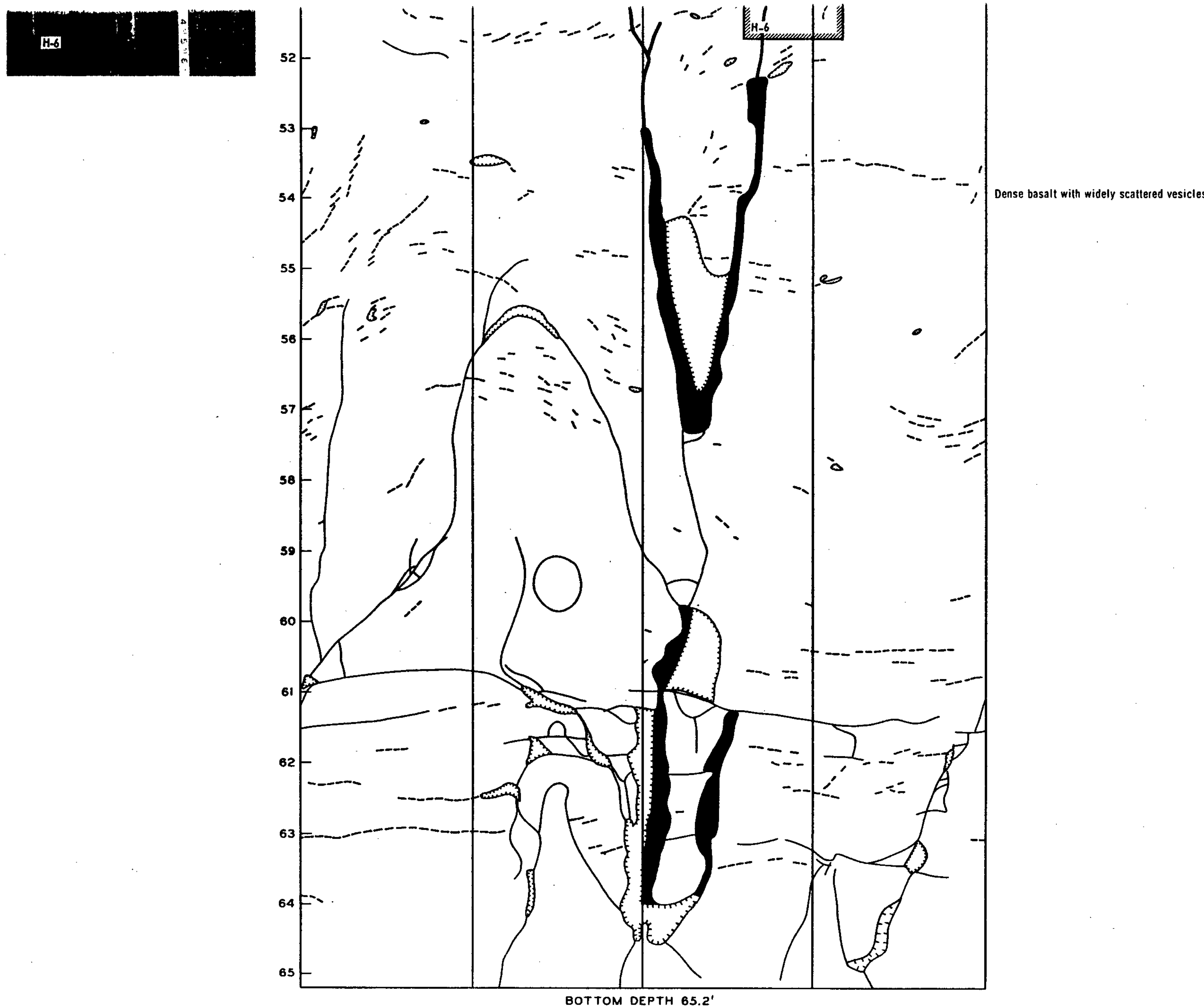


Figure B.4 Log of calyx Hole U18H (Continued).

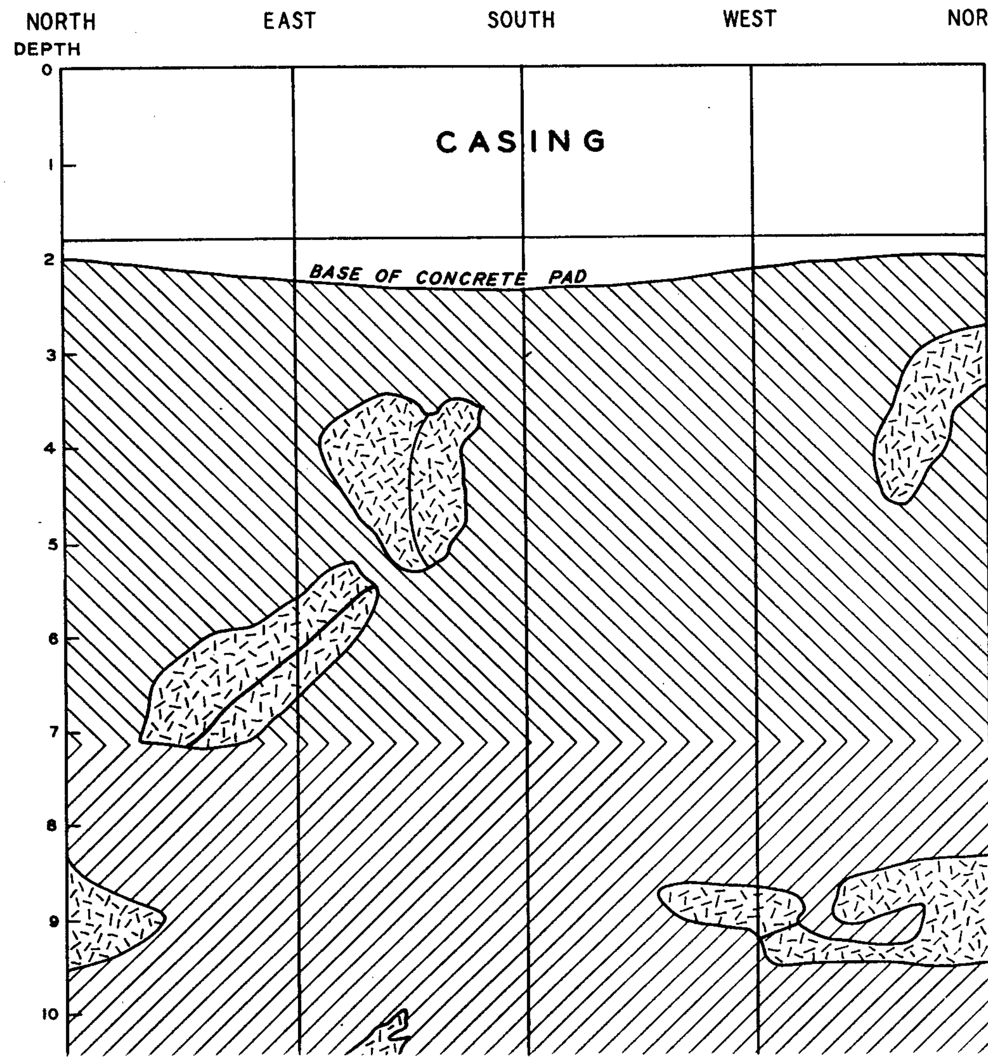
3

LOG OF CALYX HOLE

PROJECT: DUGOUT	HOLE NO.: U 18 I
ELEVATION: 5386.61	LOCATION: N853,289.94 E594,030.06
TOTAL DEPTH: 64.0 FT	HOLE DIAMETER: 36 IN.

PHOTOGRAPH

SECTION



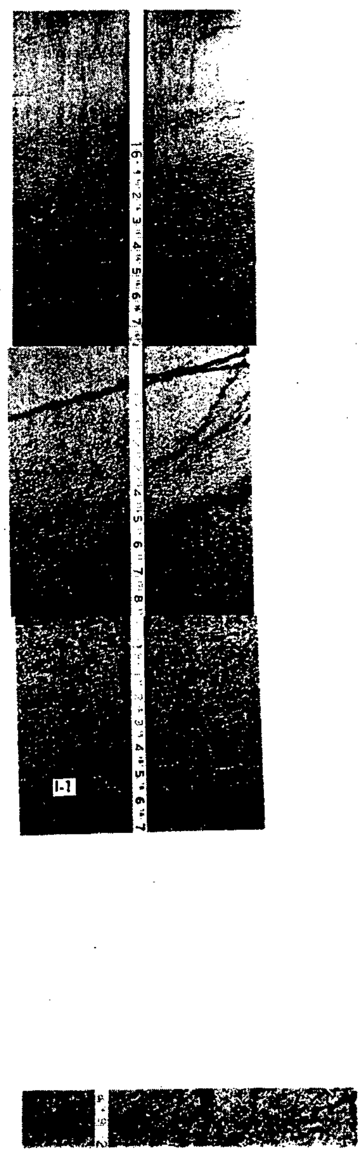
REMARKS

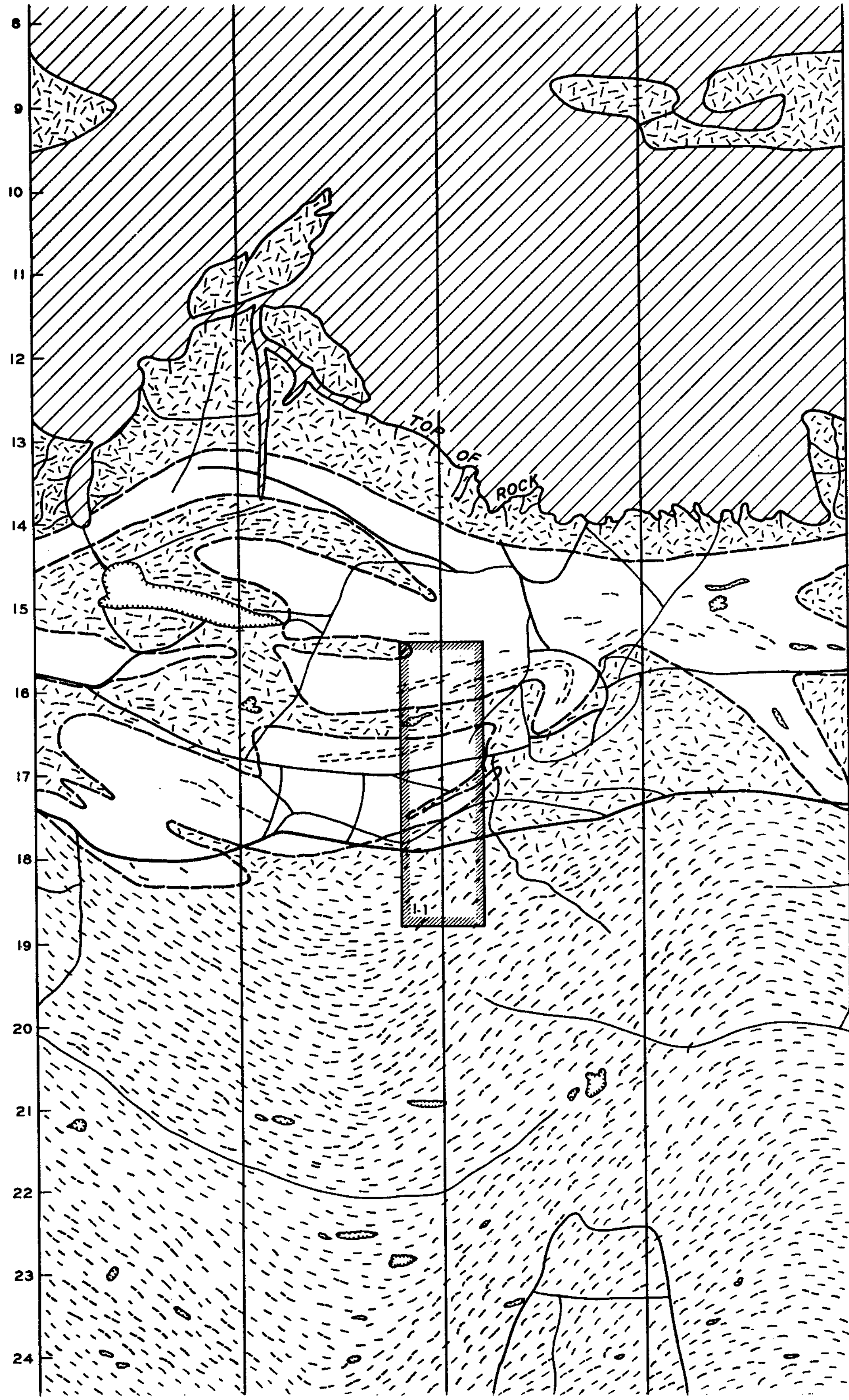
Tan, silty sand with caliche and fragments and boulders of vesicular basalt.

Cindery material, brick red. 7.1 ft.

1

2





Cindery material, brick red, 7.1 ft.

Vesicular basalt. 20% vesicles that average 1/8 to 1/4 in. in length, with random orientation.

Dense basalt with scattered vesicles.

Vesicular basalt. 20% vesicles that average 1/8 to 1/4 in. in length, with random orientation.

Vesicular basalt. 25% vesicles, that average 1/4 to 1/2 in. in length, range up to 4 in. in length and 1 in. in width, dipping 30 to 40 degrees southeast.

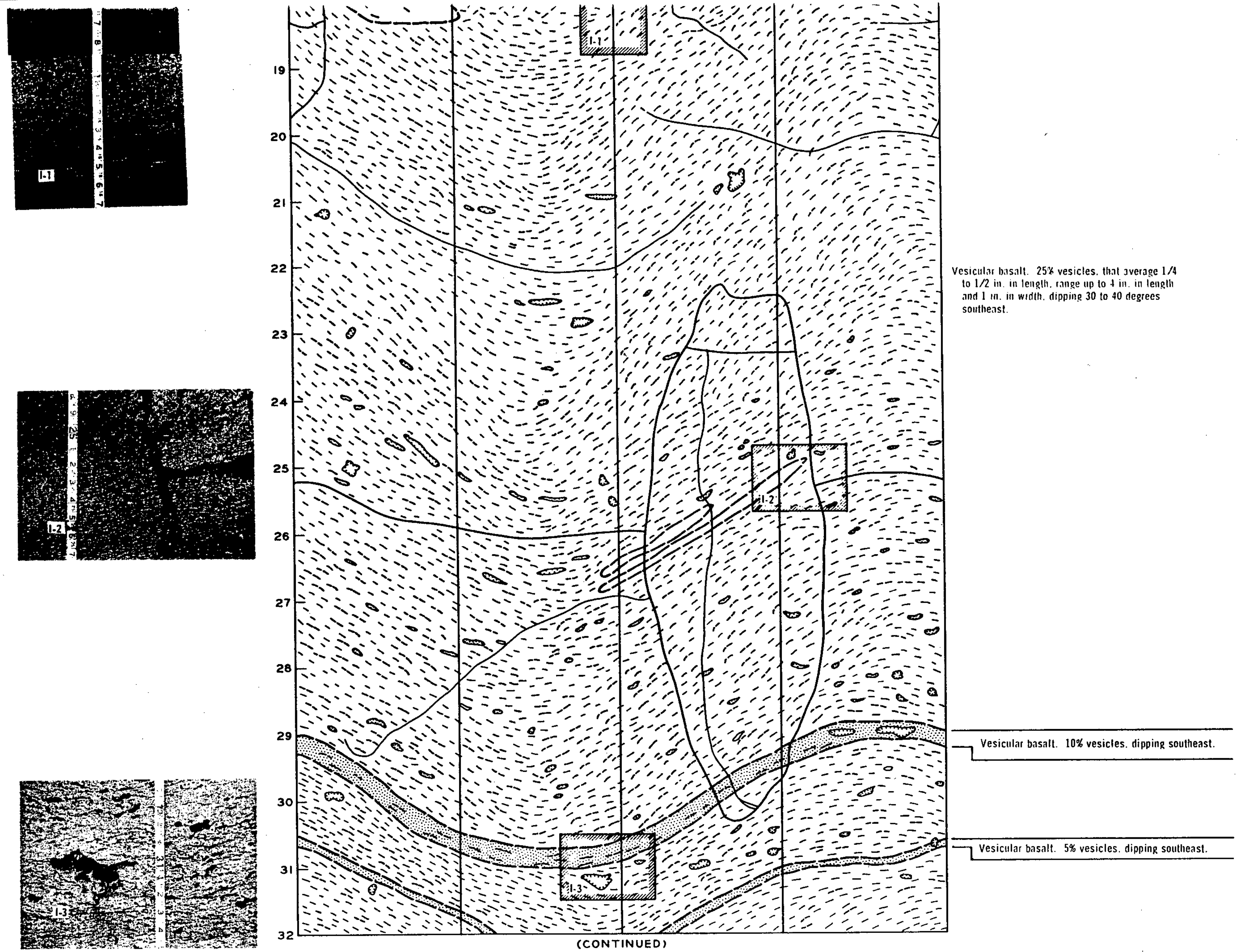


Figure B.5 Log of calyx Hole U18I.

3

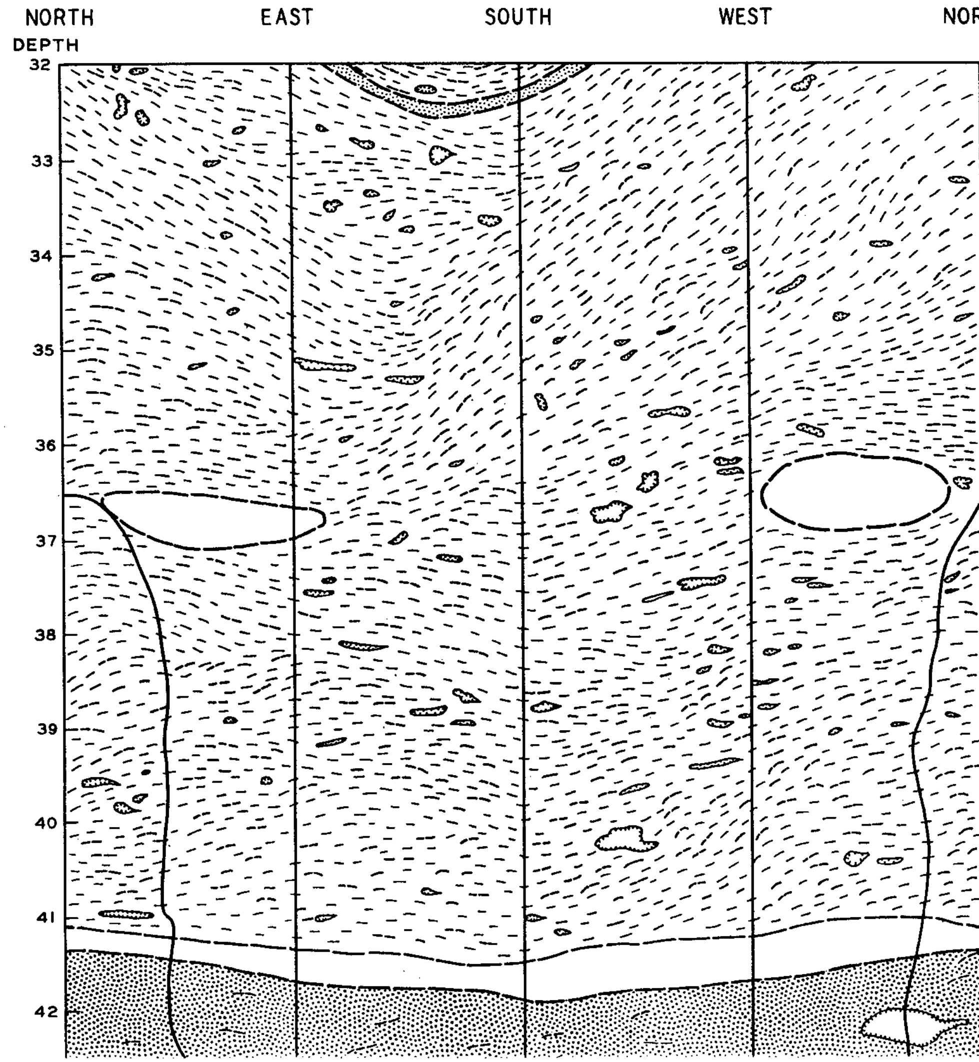
(CONTINUED)

LOG OF CALYX HOLE

PROJECT: DUGOUT	HOLE NO.: U 18 I
ELEVATION: 5386.61	LOCATION: N853,289.94 E594,030.06
TOTAL DEPTH: 64.0 FT	HOLE DIAMETER: 36 IN.

PHOTOGRAPH

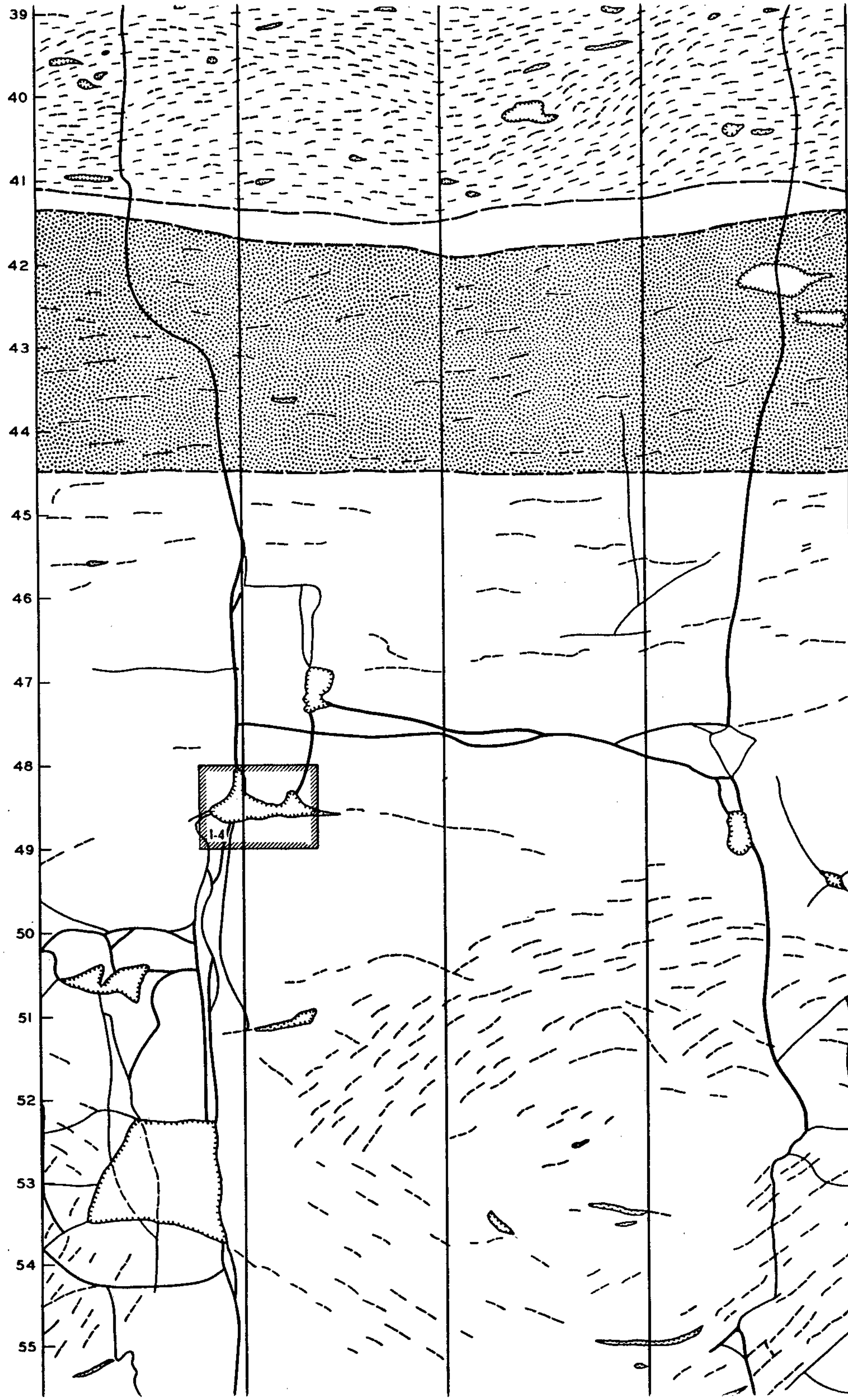
SECTION



REMARKS

Vesicular basalt. 20% vesicles, that average 1/4 to 1/2 in. in length, dipping southeast; lenses of dense basalt.

Dense basalt with widely scattered vesicles.



Dense basalt with widely scattered vesicles.

Vesicular basalt. 10 to 15% vesicles, that range up to 4 in. in length, and 1/8 in. in width. Most vesicles range from 1/2 to 2 in. in length and 1/8 in. in width and are horizontal.

Dense basalt with widely scattered vesicles.

2

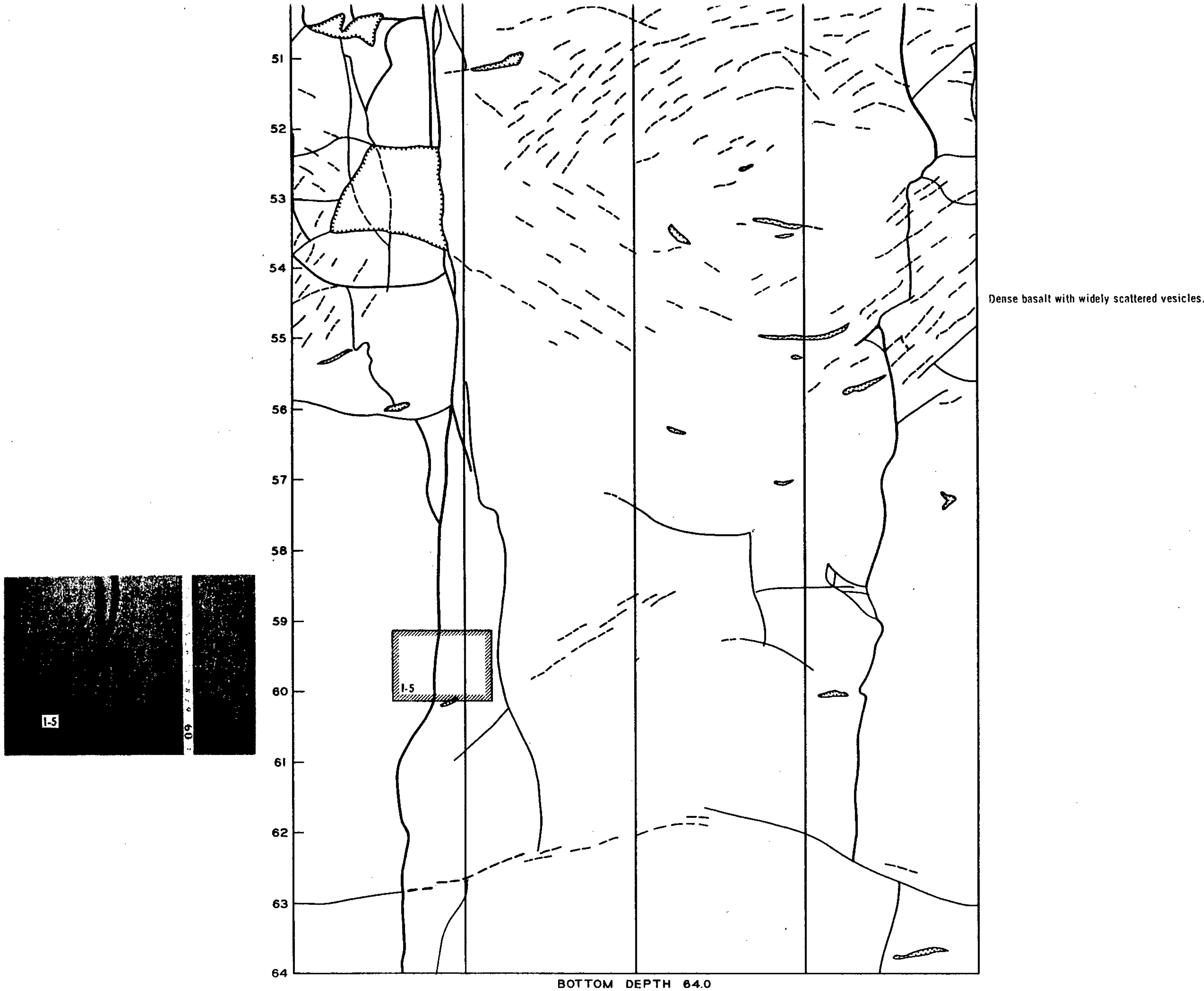


Figure B.6 Log of calyx Hole U18I (Continued).

3

LOG OF CALYX HOLE

PROJECT: DUGOUT

ELEVATION: 5387.66

TOTAL DEPTH: 64.0 FT

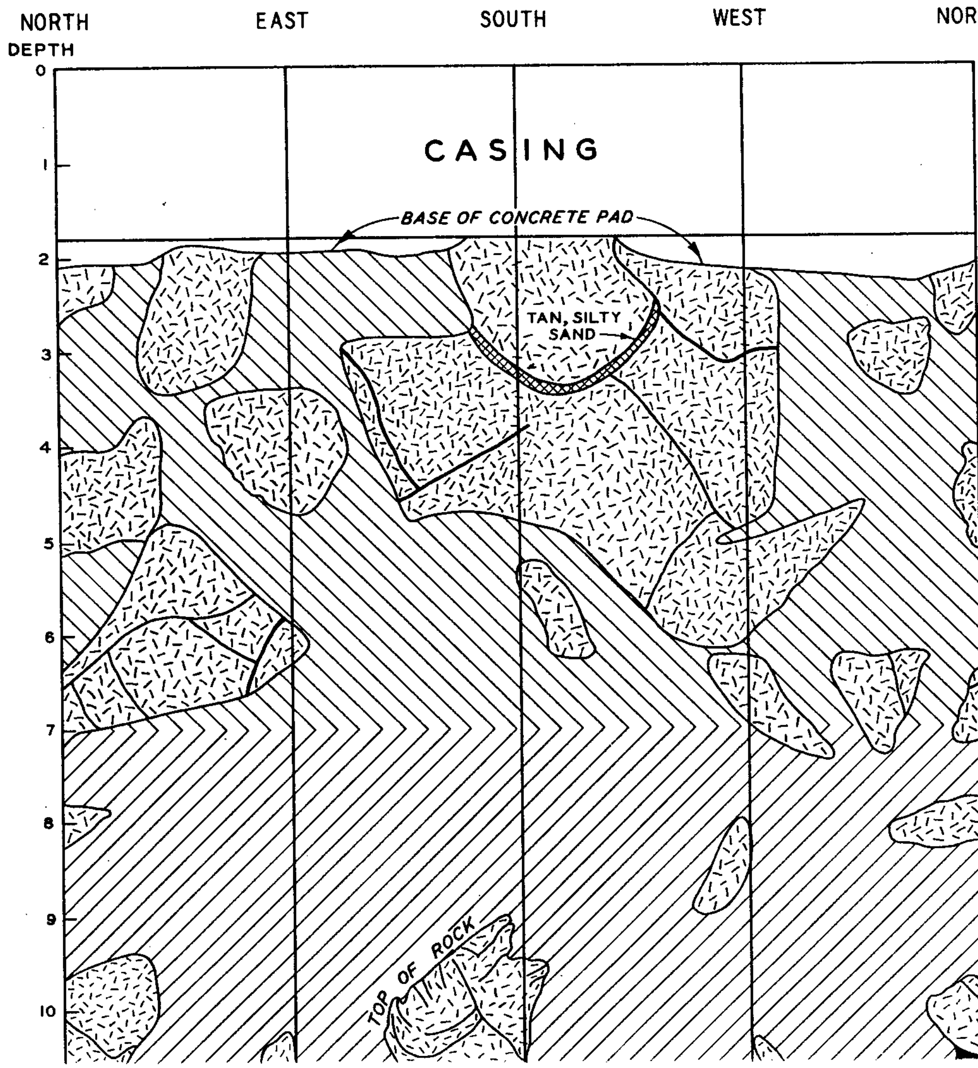
HOLE NO.: U18J

LOCATION: N853,290.00 E593,985.12

HOLE DIAMETER: 36 IN.

PHOTOGRAPH

SECTION

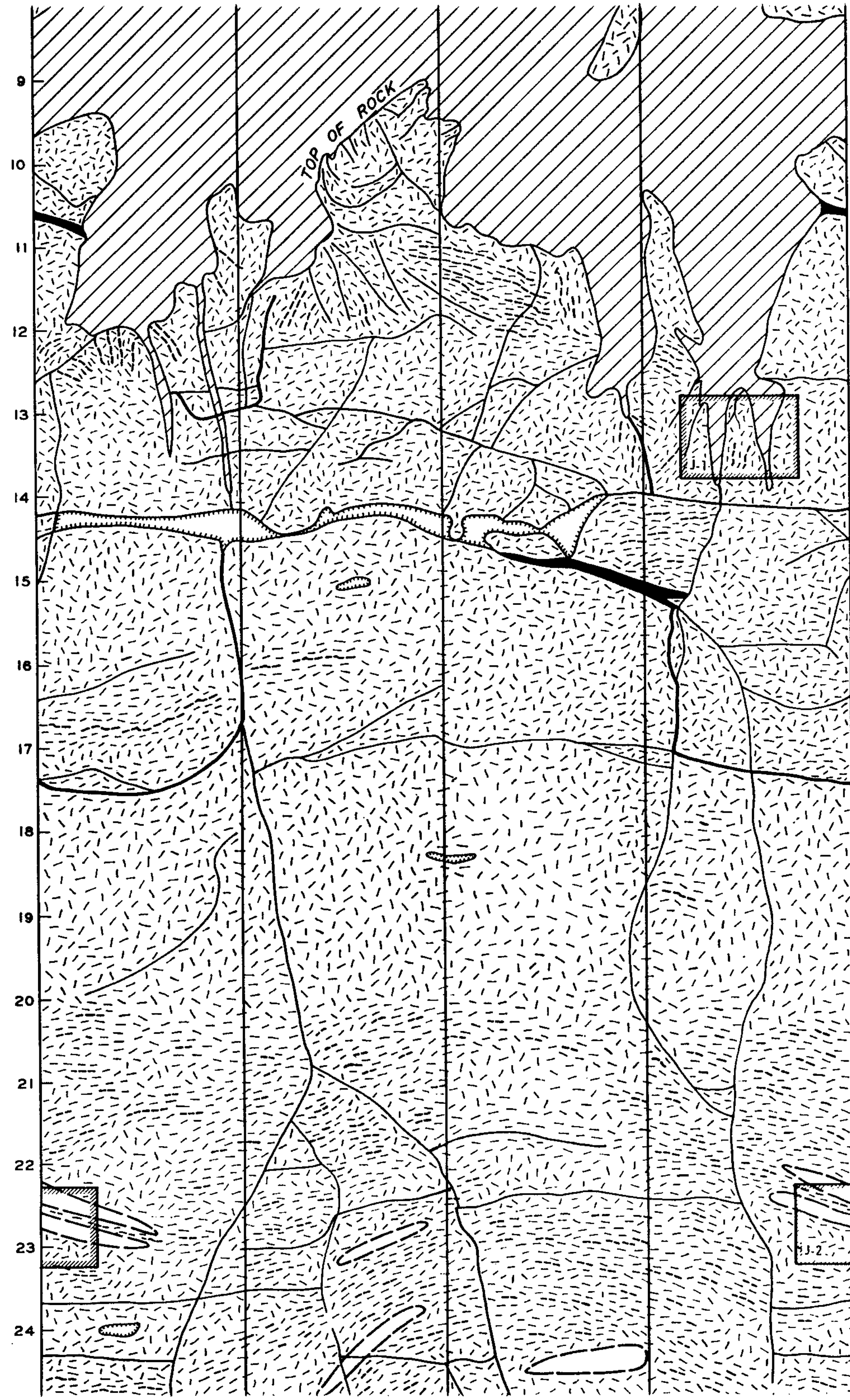


REMARKS

Tan, silty sand with caliche and fragments and boulders of vesicular basalt, with cindery material present.

Vesicular basalt. 25% vesicles that range up to 3 in. in length and 1 in. in width, average 1/8 to 1/4 in. in length, with random orientation

(1)



Vesicular basalt. 25% vesicles that range up to 3 in. in length and 1 in. in width, average 1/8 to 1/4 in. in length, with random orientation.

25% vesicles, that average 1/4 to 1/2 in. long. Most vesicles dip 10 to 15 degrees northeast, some layers and lenses of dense basalt.

(2)

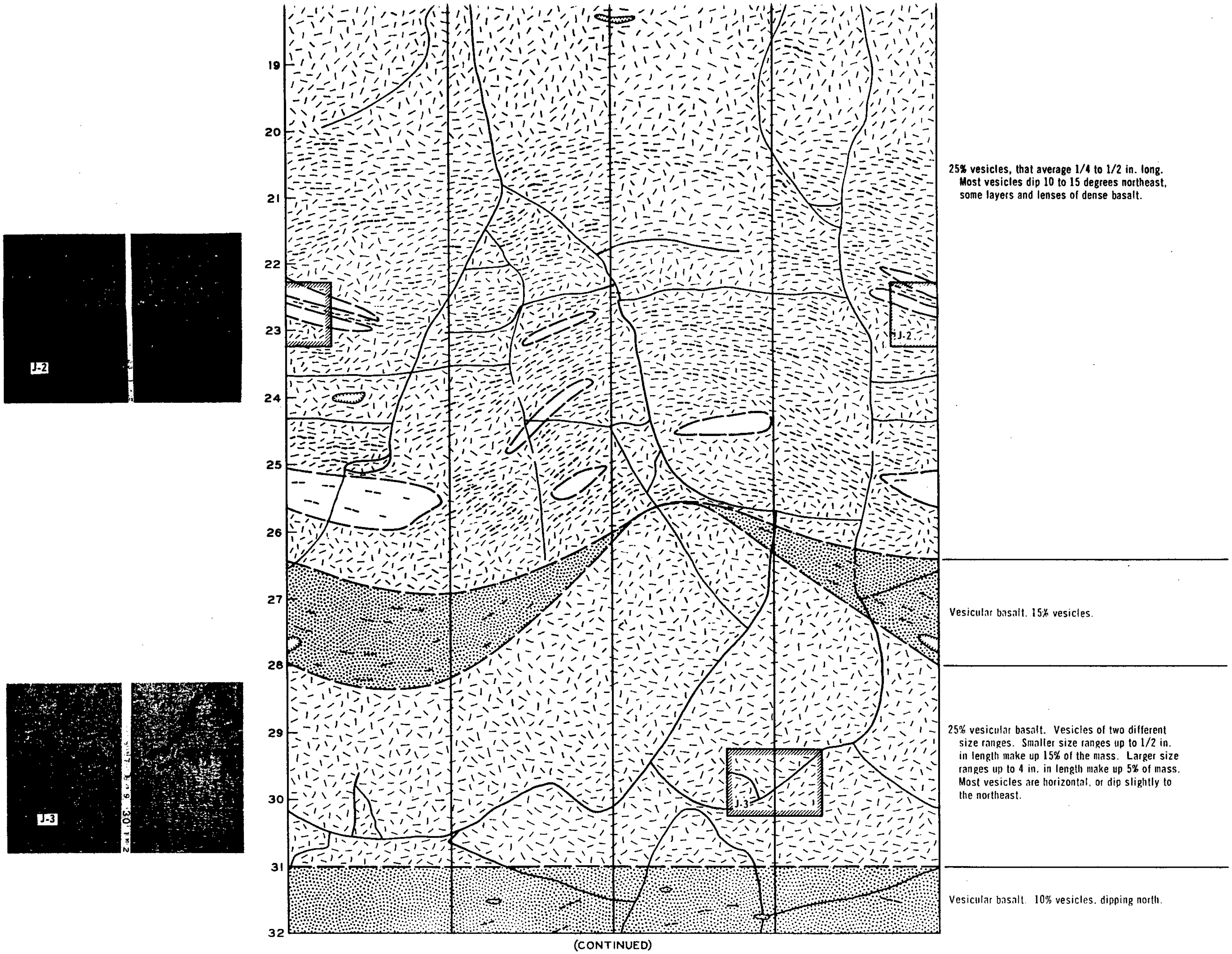


Figure B.7 Log of calyx Hole U18J.

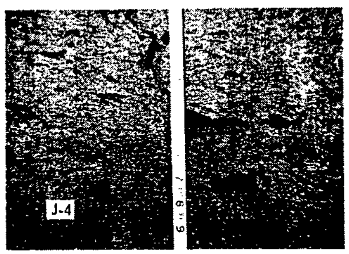
③

(CONTINUED)

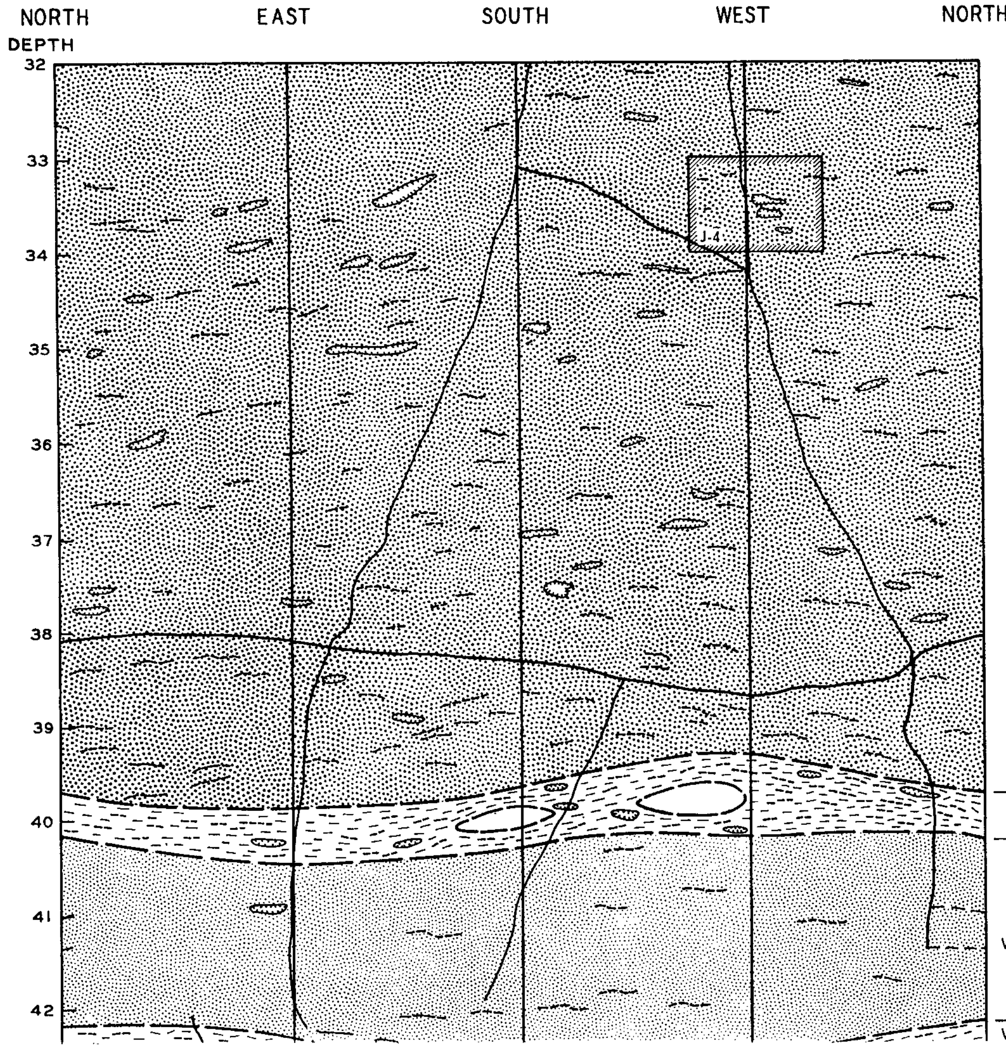
LOG OF CALYX HOLE

PROJECT: DUGOUT	HOLE NO.: U18J
ELEVATION: 5387.66	LOCATION: N853,290.00 E593,985.12
TOTAL DEPTH: 64.0 FT	HOLE DIAMETER: 36 IN.

PHOTOGRAPH



SECTION

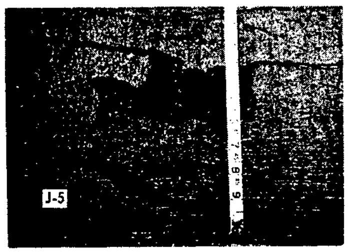


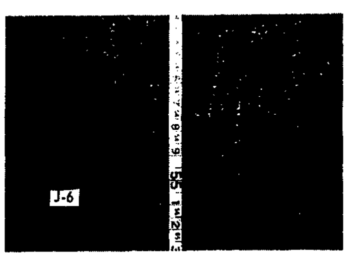
REMARKS

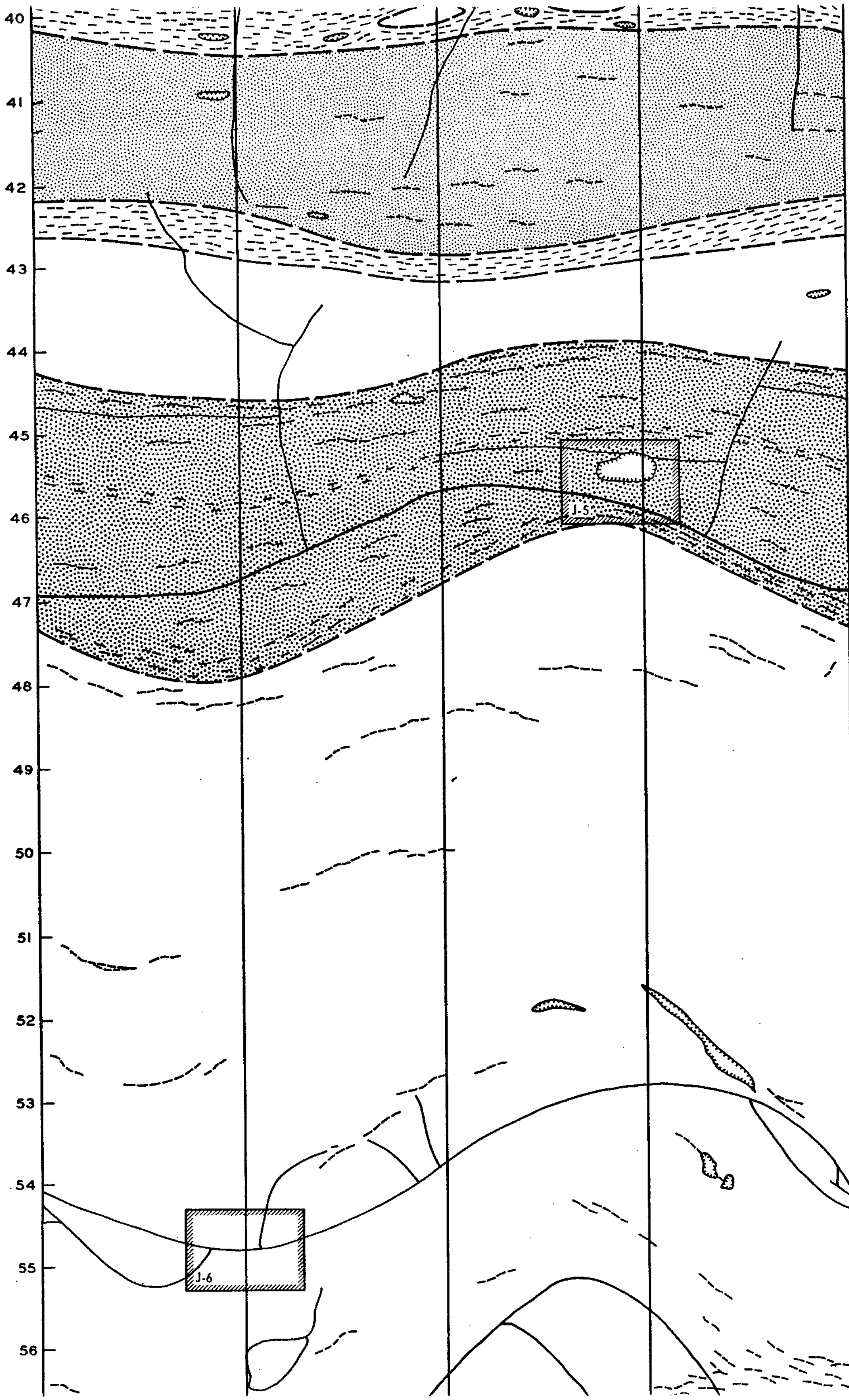
Vesicular basalt. 20% vesicles that range up to 1 in. in length and 1/8 in. in width, with lenses of dense basalt.

Vesicular basalt. 5% vesicles, and are horizontal.

Vesicular basalt. 20% vesicles that range up to 2 in.







Vesicular basalt. 20% vesicles that range up to 1 in. in length and 1/8 in. in width, with lenses of dense basalt.

Vesicular basalt. 5% vesicles, and are horizontal.

Vesicular basalt. 20% vesicles that range up to 2 in. in length and 1/8 in. in width.

Dense basalt with widely scattered vesicles.

Vesicular basalt. 15% vesicles that form alternating layers of highly vesicular and vesicular basalt, dipping 20 degrees northeast.

Dense basalt with widely scattered vesicles.

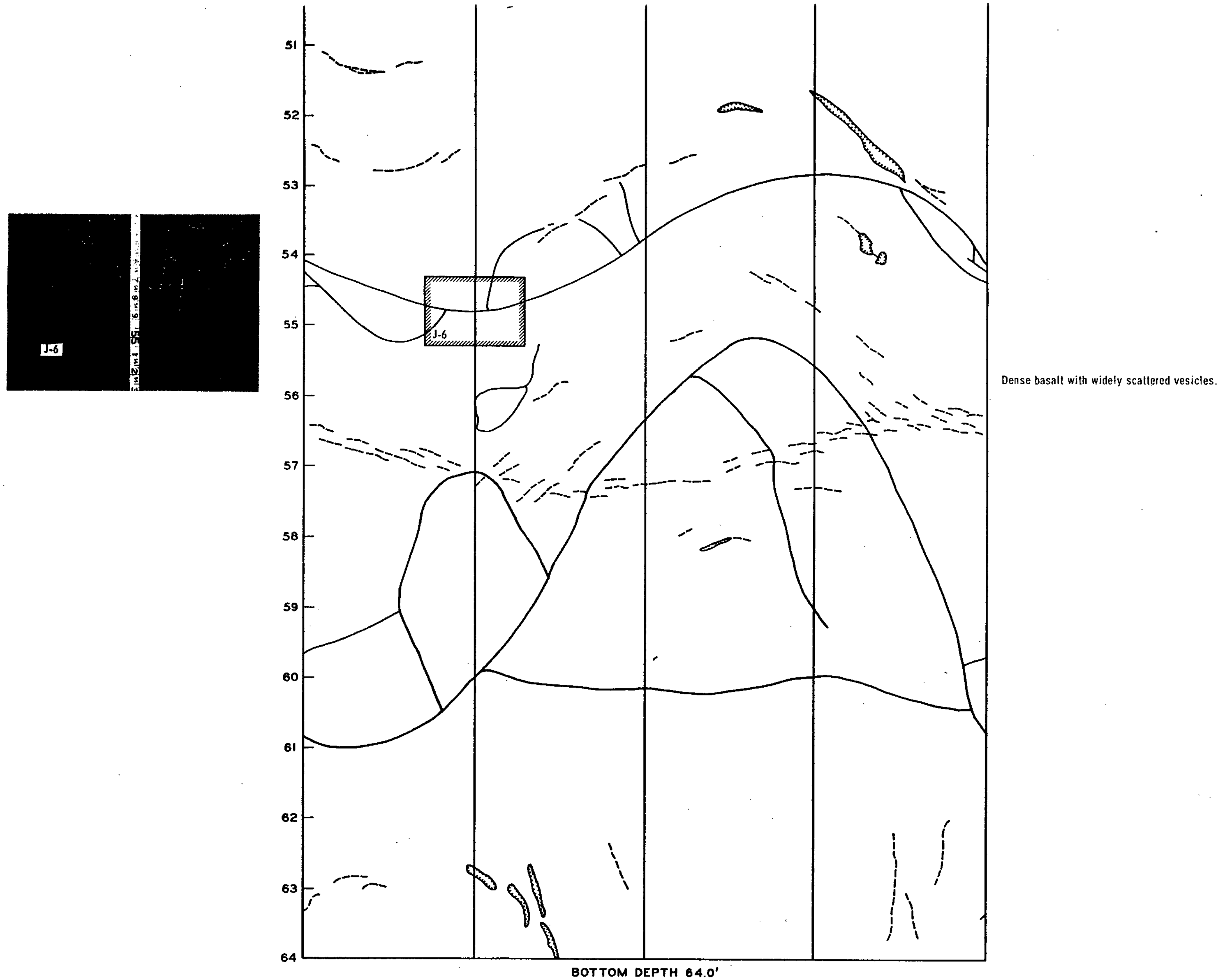


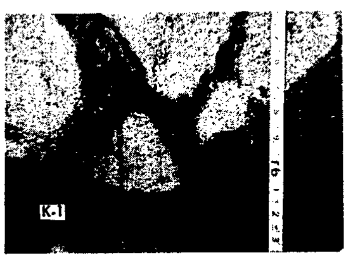
Figure B.8 Log of calyx Hole U18J (Continued).

3

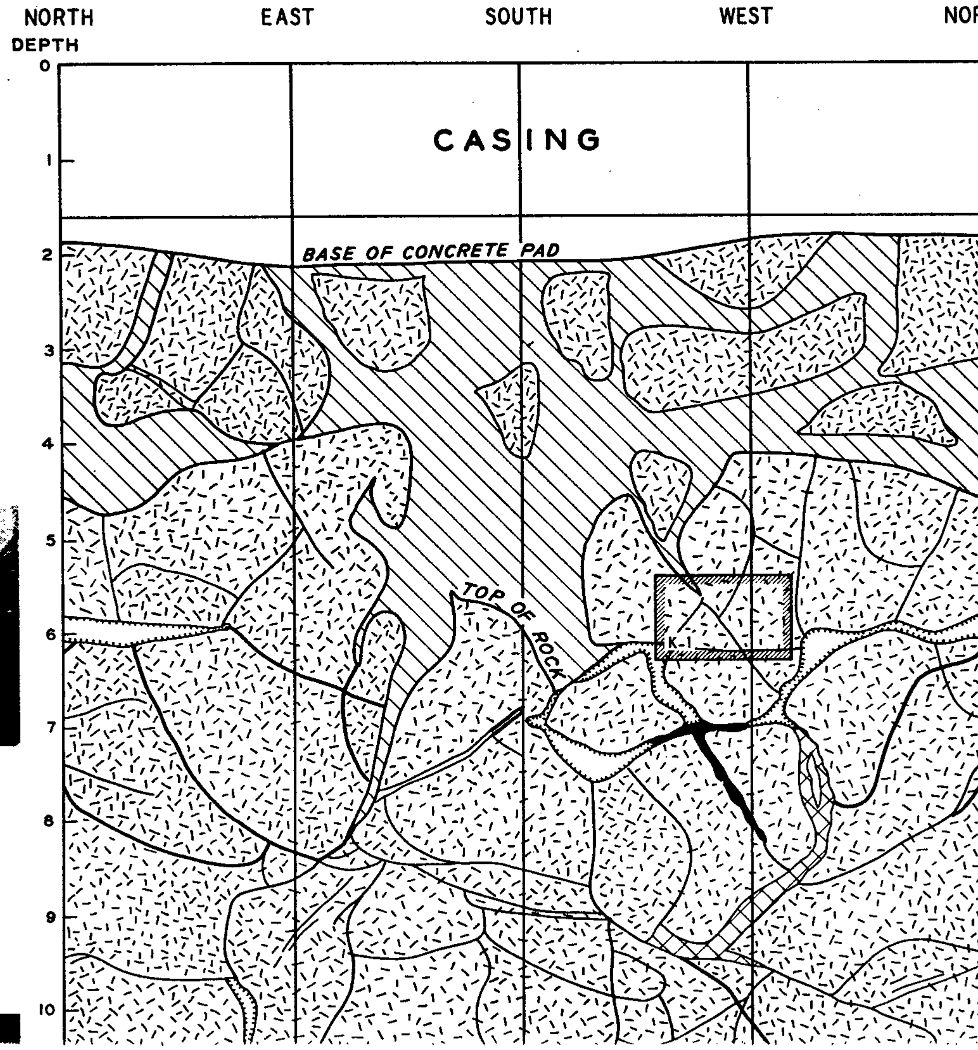
LOG OF CALYX HOLE

PROJECT: DUGOUT	HOLE NO.: U 18 K
ELEVATION: 5387.66	LOCATION: N853,290.10 E593,940.00
TOTAL DEPTH: 64.2 FT	HOLE DIAMETER: 36 IN.

PHOTOGRAPH



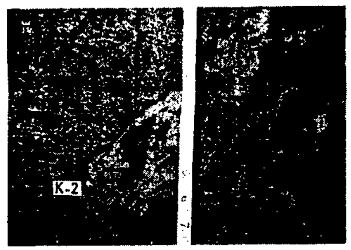
SECTION

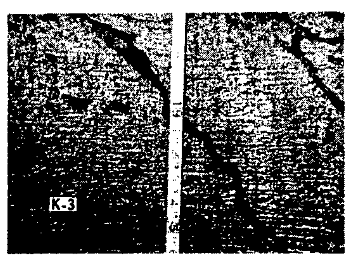


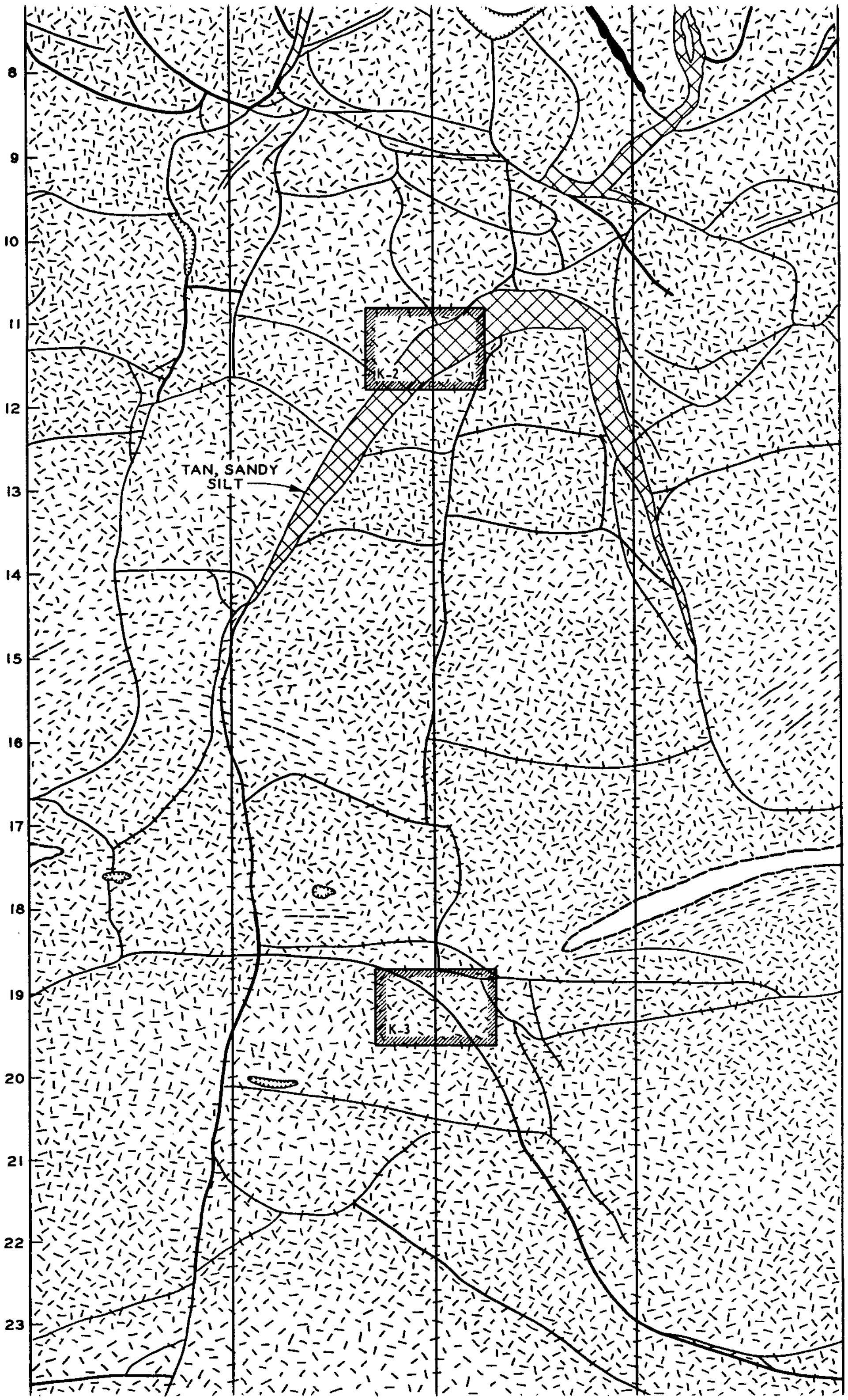
REMARKS

Tan, silty sand with caliche and fragments and boulders of vesicular basalt.

1

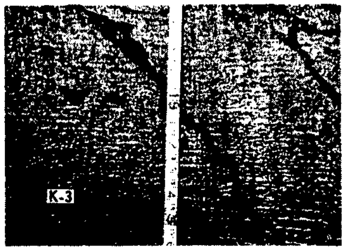


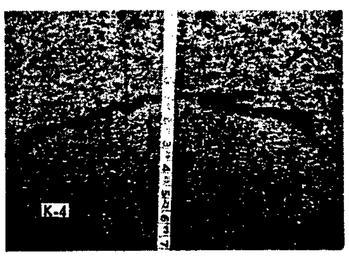


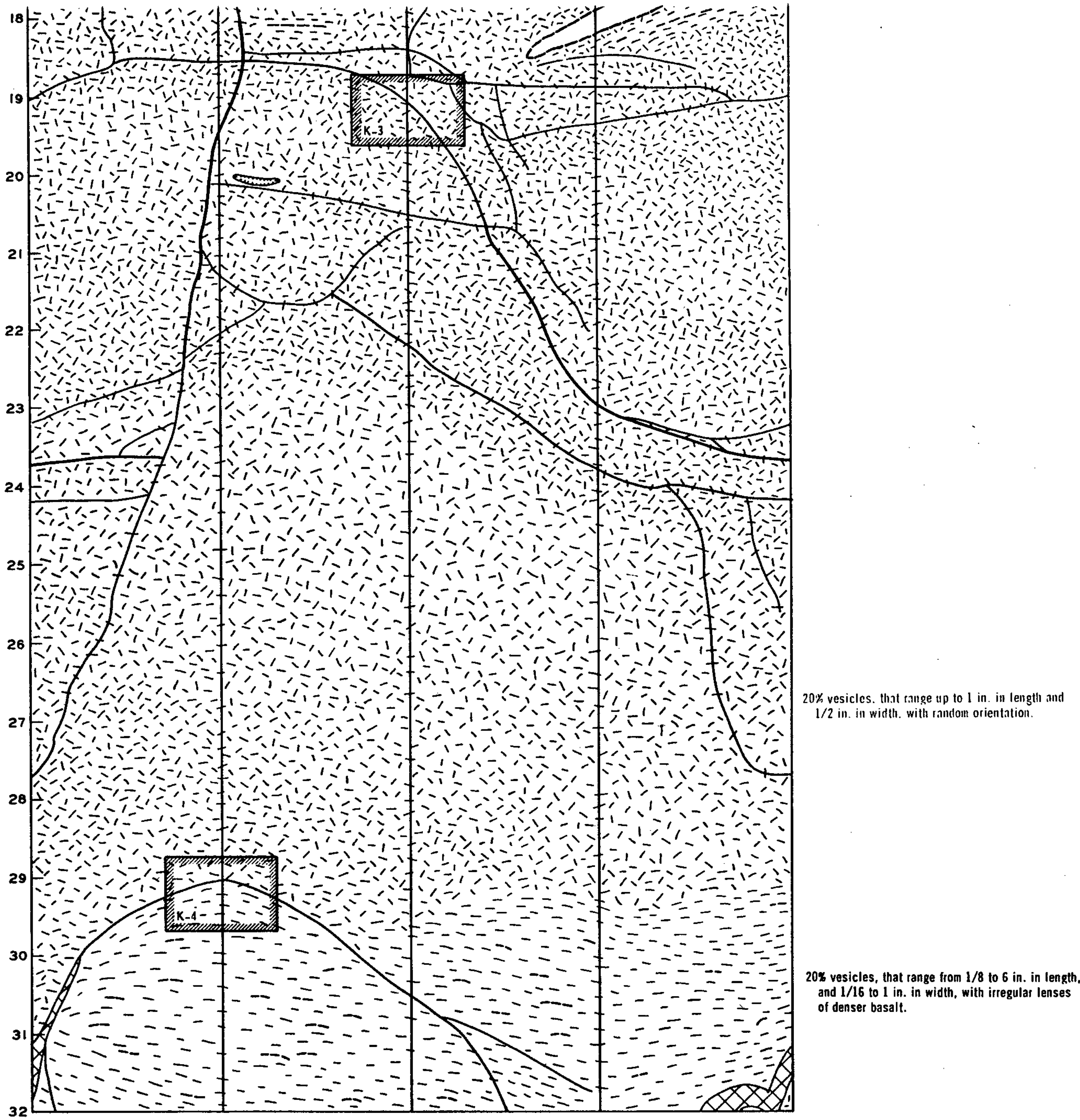


Vesicular basalt. 25% vesicles, that average 1/8 to 1/4 in. in length, with random orientation.

(2)







(CONTINUED)

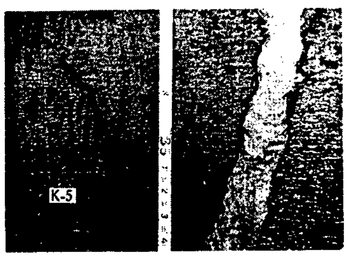
Figure B.9 Log of calyx Hole U18K.

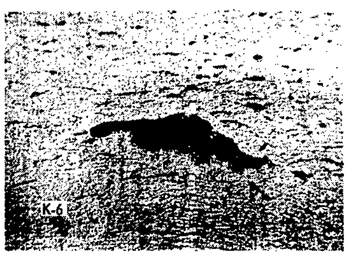
(CONTINUED)

LOG OF CALYX HOLE

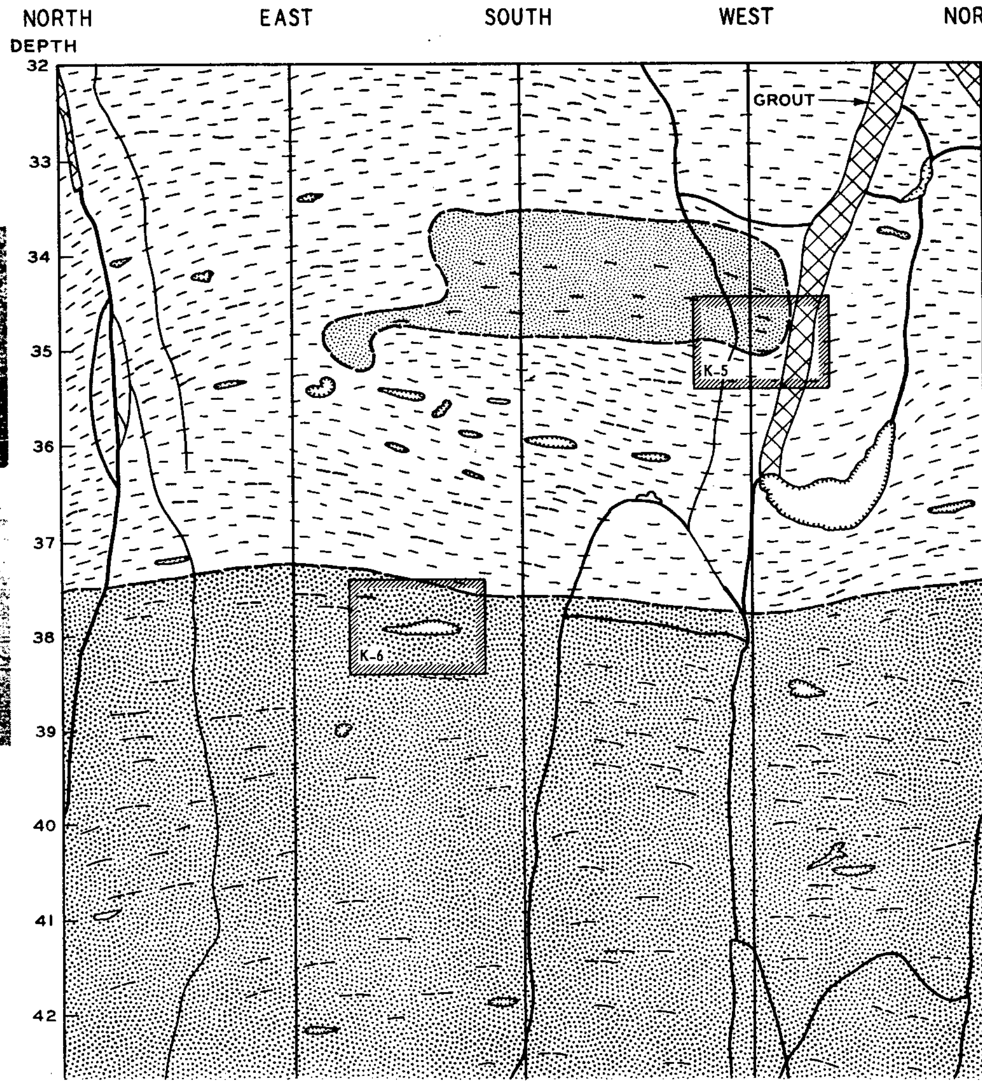
PROJECT: DUGOUT	HOLE NO.: U 18 K
ELEVATION: 5387.66	LOCATION: N853,290.10 E593,940.00
TOTAL DEPTH: 64.2 FT	HOLE DIAMETER: 36 IN.

PHOTOGRAPH



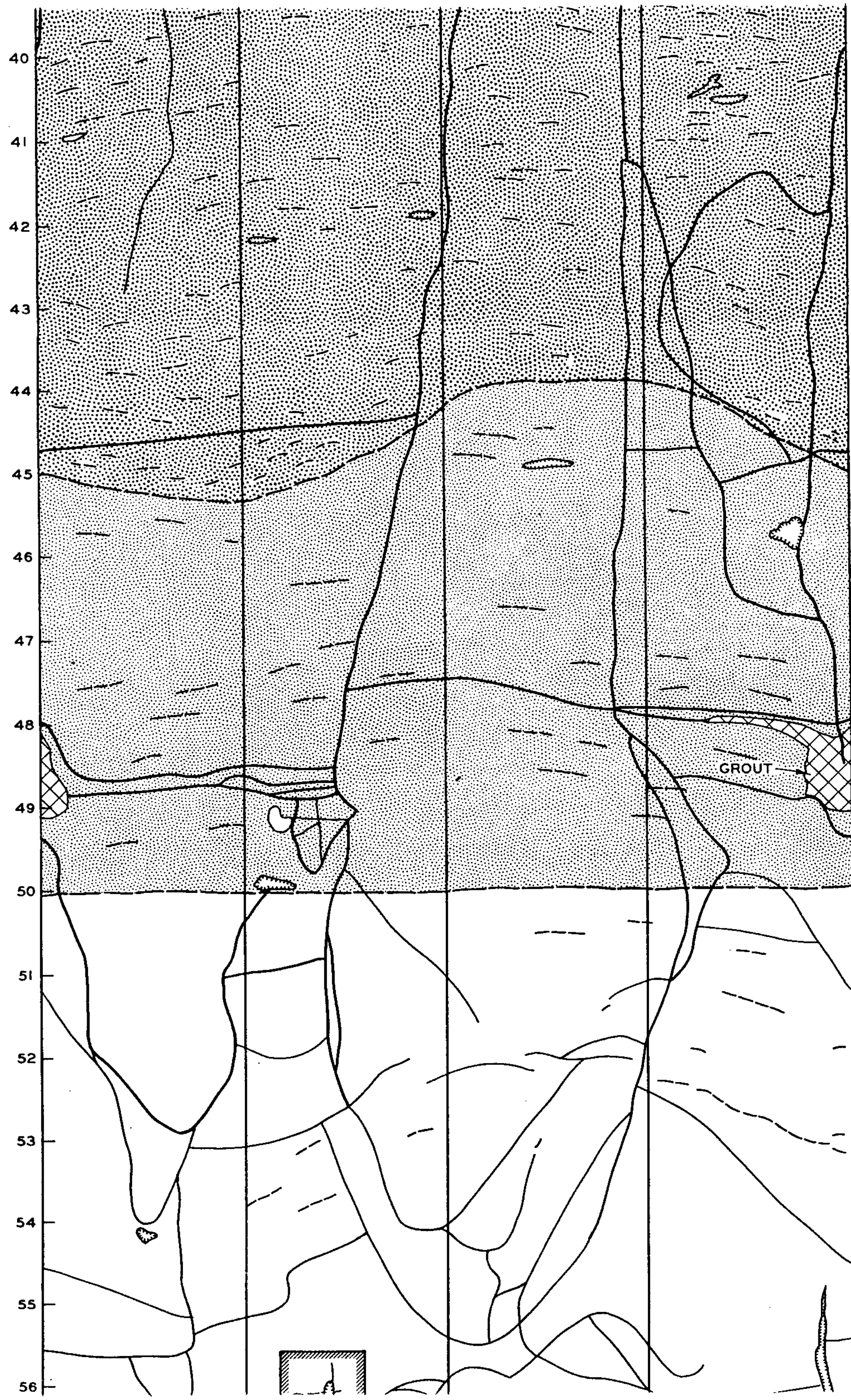


SECTION



REMARKS

Vesicular basalt. 10% vesicles that average 1/8 in. in width, arranged in flow lines up to 6 in. long.



Vesicular basalt. 10% vesicles that average 1/8 in. in width, arranged in flow lines up to 6 in. long.

Vesicular basalt. 5% vesicles, average 1/8 in. in width, arranged in flow lines up to 1 ft long, dipping 10 to 20 degrees northeast.

②

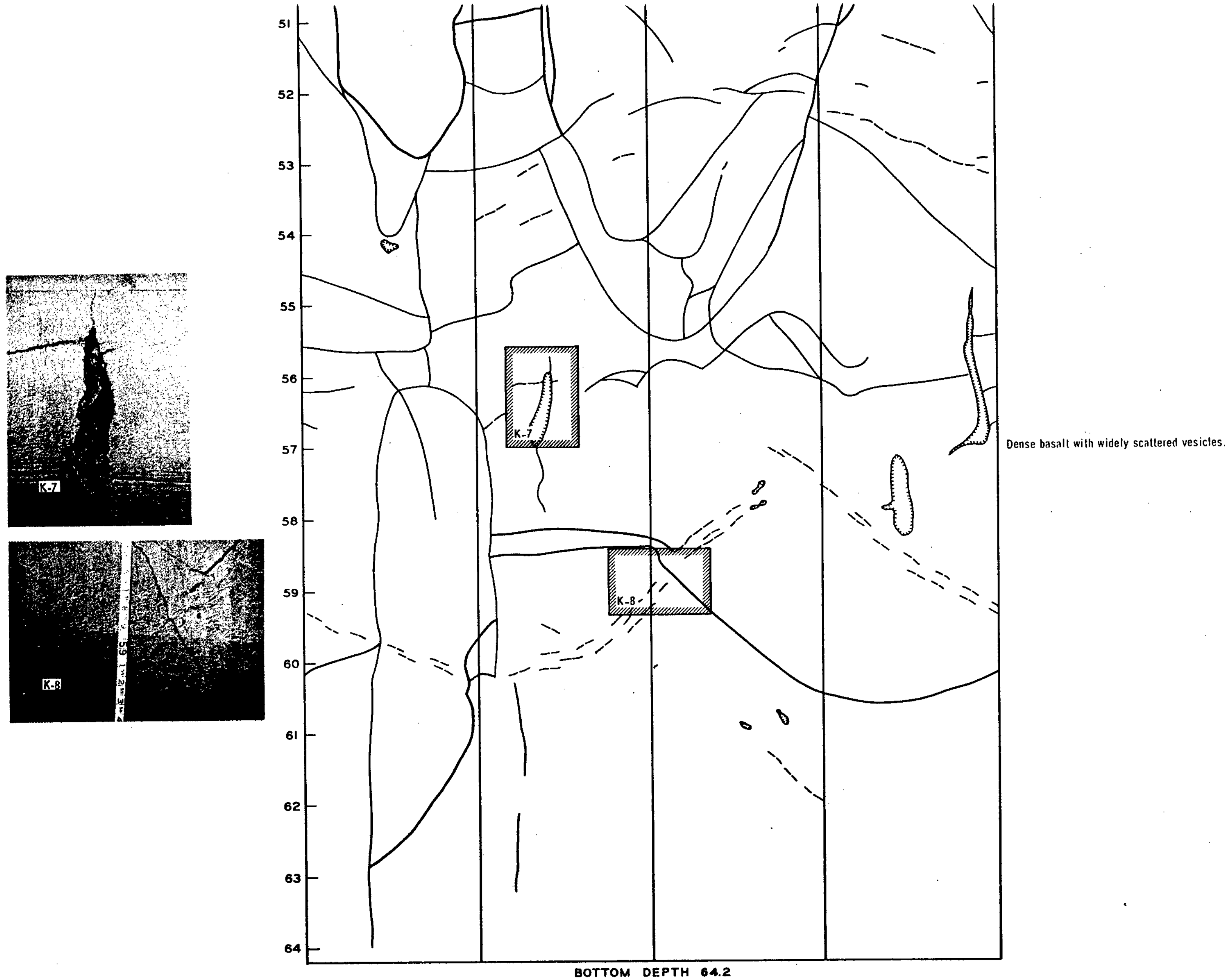


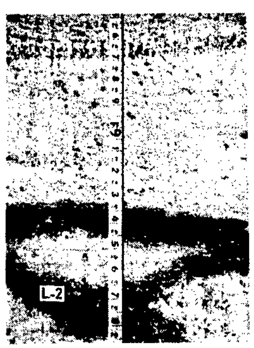
Figure B.10 Log of calyx Hole U18K (Continued).

(3)

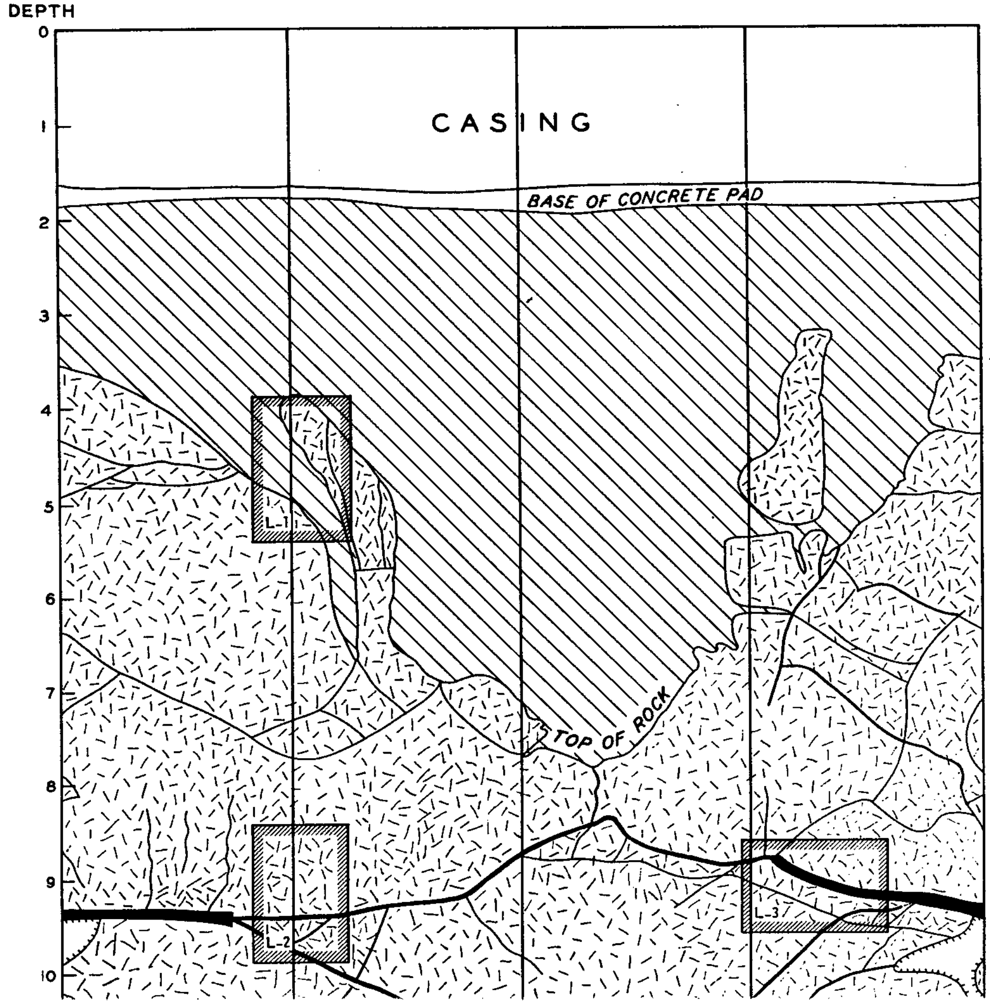
LOG OF CALYX HOLE

PROJECT: DUGOUT	HOLE NO.: U 18 L
ELEVATION: 5388.12	LOCATION: N853,290.00 E593,895.02
TOTAL DEPTH: 64.0 FT	HOLE DIAMETER: 36 IN.

PHOTOGRAPH



SECTION

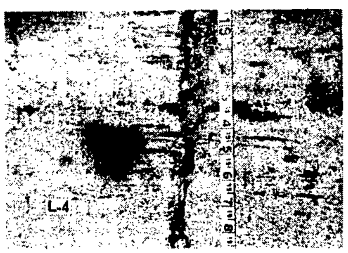


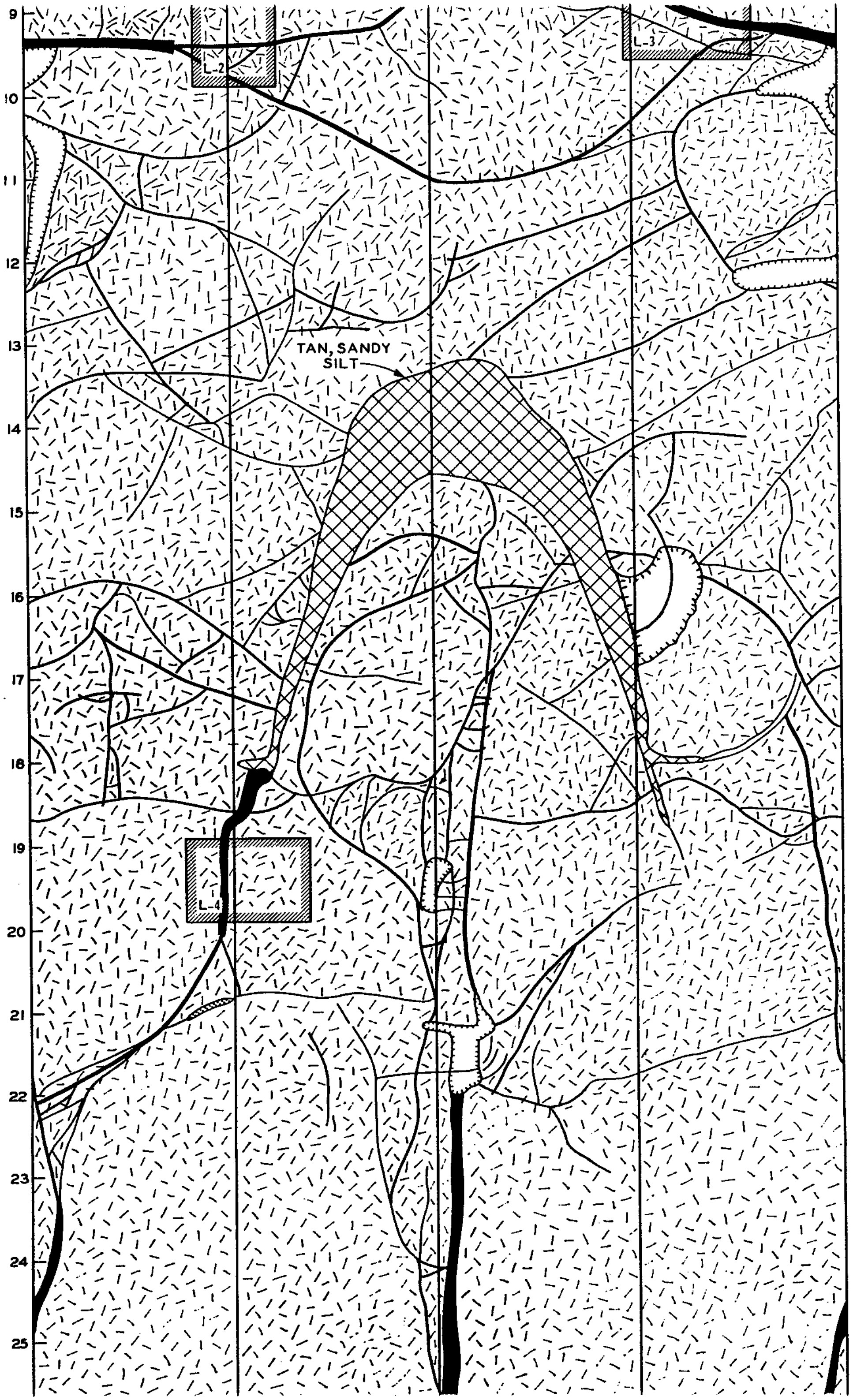
REMARKS

Tan, silty sand with caliche and fragments of vesicular basalt.

Vesicular basalt. 25 to 35% vesicles, average 1/4 in. in length, few vesicles up to 1/2 in. in length, 1/4 in. wide, with random orientation.

1





25 to 35% vesicles, average 1/4 in. in length. Many vesicles range up to 1 in. in length and 1/8 in. in width, and are horizontal.

②

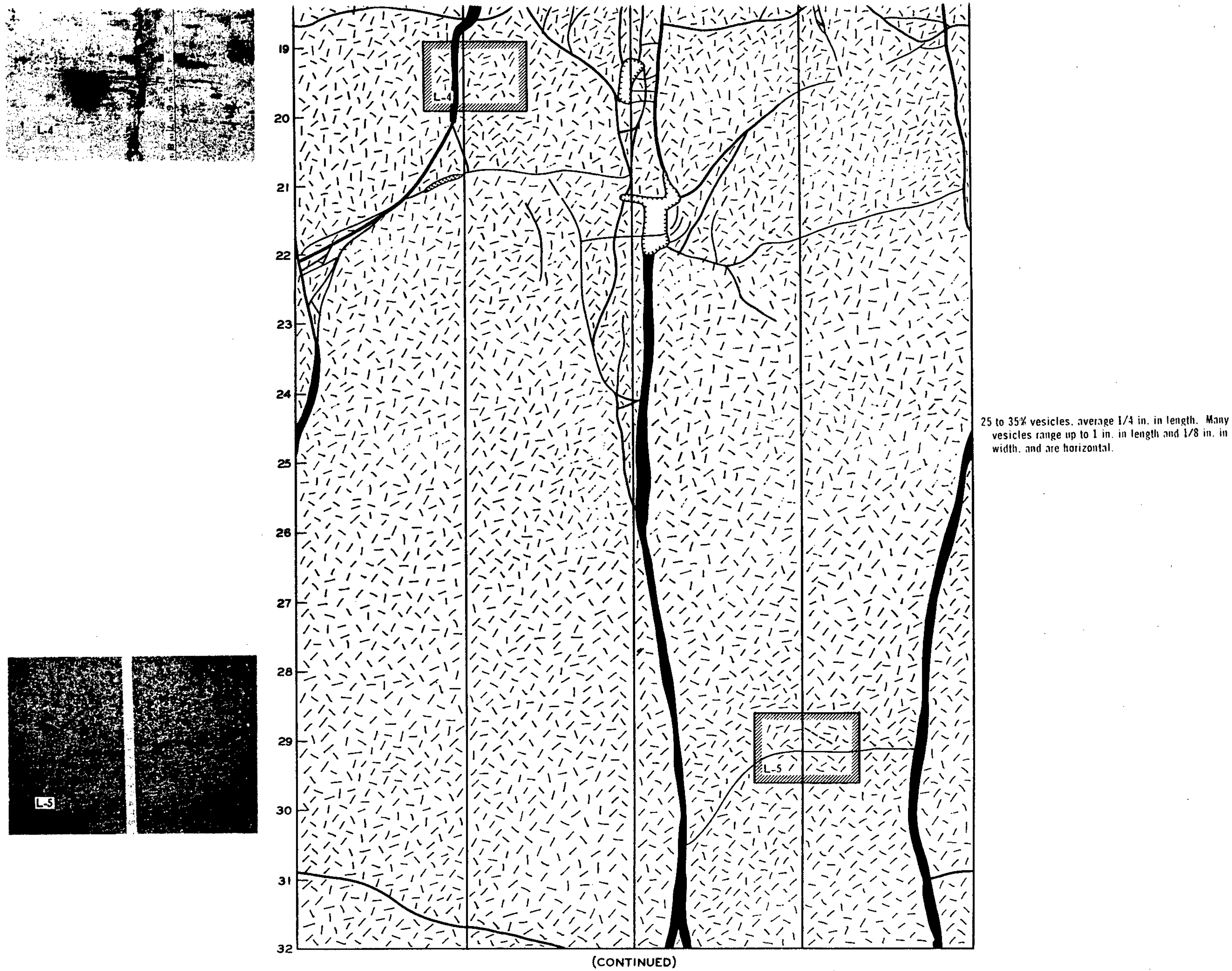


Figure B.11 Log of calyx Hole U18L.

③

(CONTINUED)

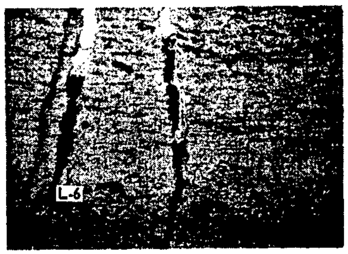
LOG OF CALYX HOLE

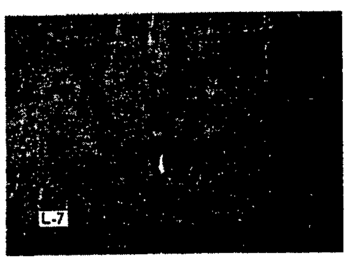
PROJECT: DUGOUT | HOLE NO.: U 18 L

ELEVATION: 5388.12 | LOCATION: N853,290.00 E593,895.02

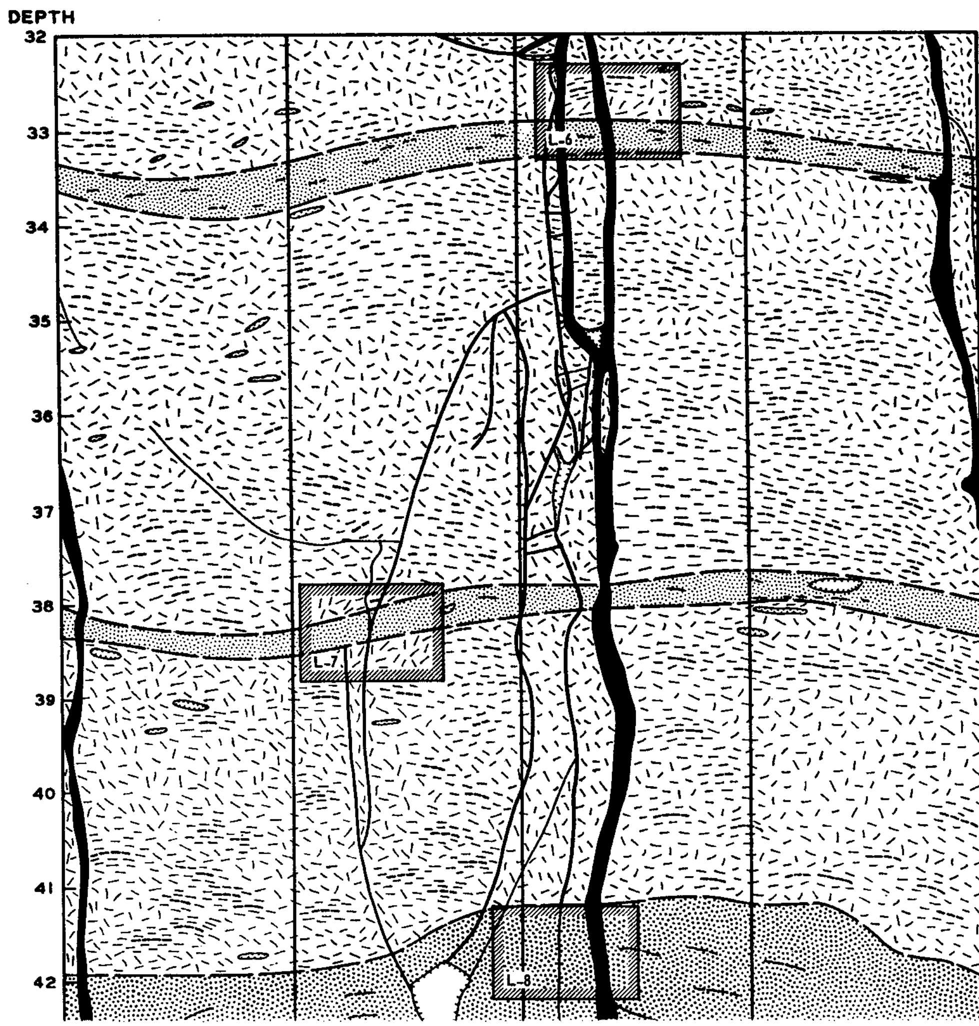
TOTAL DEPTH: 64.0 FT | HOLE DIAMETER: 36 IN.

PHOTOGRAPH





SECTION



REMARKS

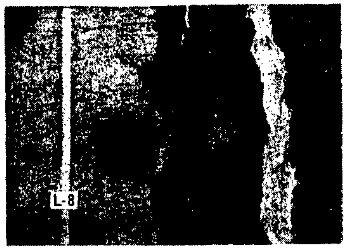
Vesicular basalt. 5% vesicles, range up to 3 in. in length and 1/8 in. in width.

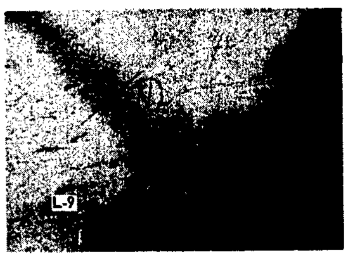
Vesicular basalt. 25% vesicles, average 1/4 in. in length. Many vesicles range up to 3 in. in length and 3/4 in. in width and are horizontal.

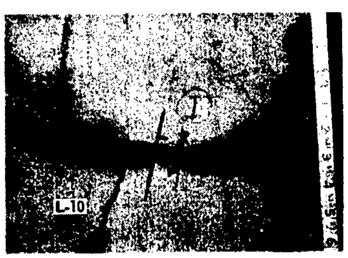
Vesicular basalt. 5% vesicles, range up to 3 in. in length and 1/8 in. in width.

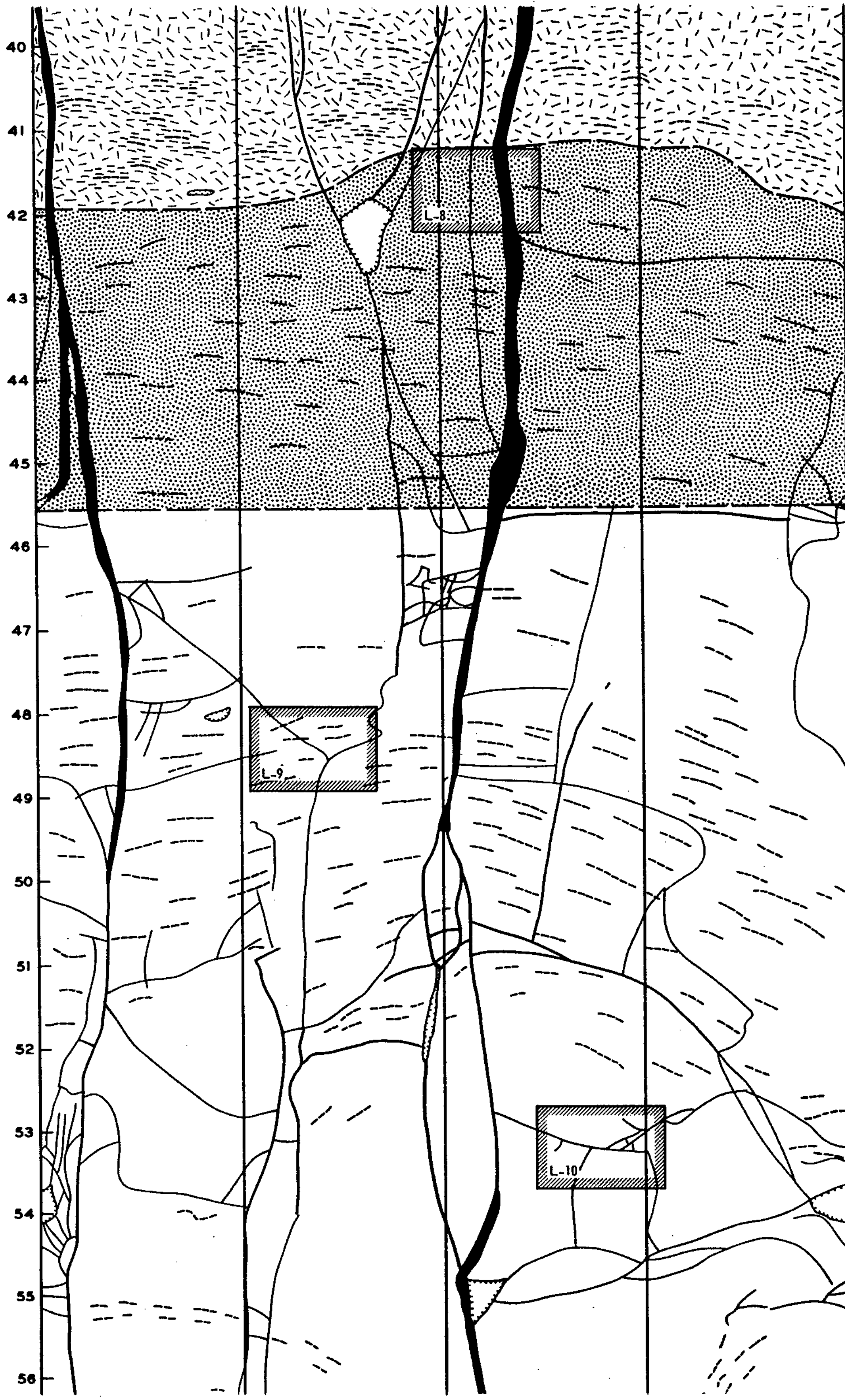
Vesicular basalt. 20% vesicles, with smaller vesicles averaging 1/4 in. in length, and vesicles up to 2 in. in length and 1/2 in. in width, with a dip to the north.

①









Vesicular basalt. 20% vesicles, with smaller vesicles averaging 1/4 in. in length, and vesicles up to 2 in. in length and 1/2 in. in width, with a dip to the north.

Vesicular basalt. 10 to 15% vesicles, range up to 6 in. in length and 1/8 in. in width, with a dip to the north.

Dense basalt with scattered vesicles.

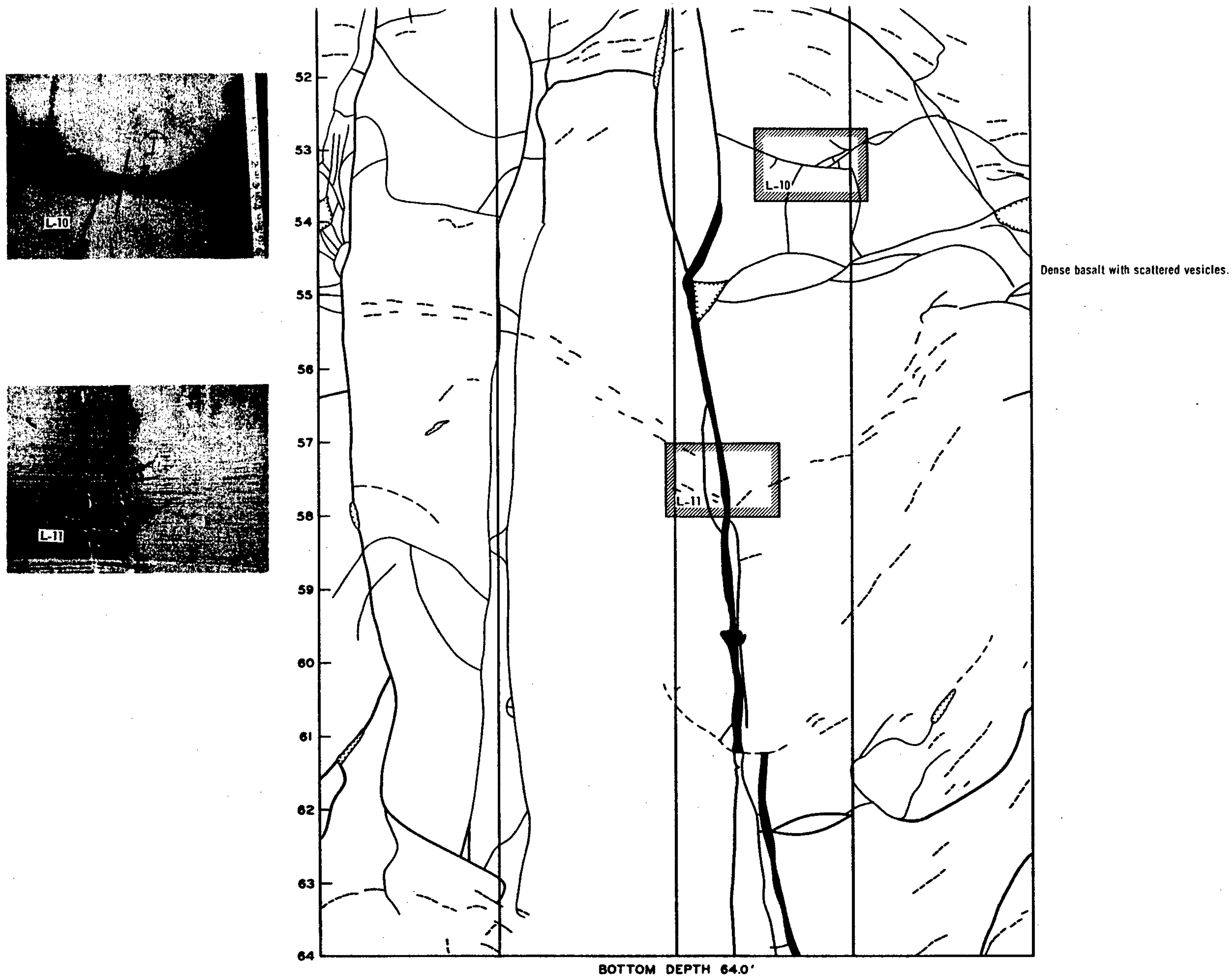


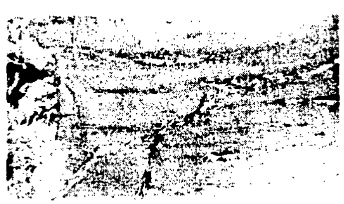
Figure B.12 Log of calyx Hole U18L (Continued).

(3)

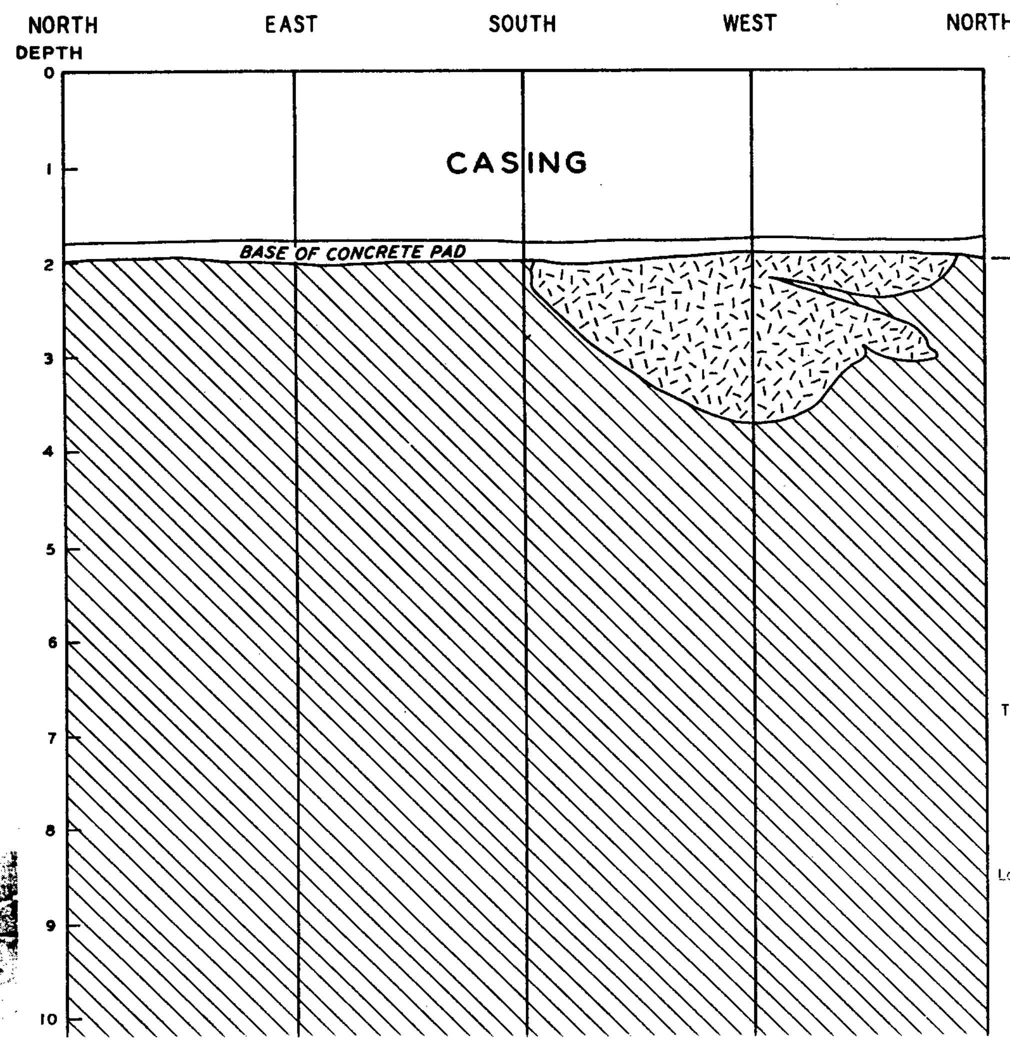
LOG OF CALYX HOLE

PROJECT: DUGOUT	HOLE NO.: U 18 M
ELEVATION: 5388.35	LOCATION: N853,290.00 E593,850.04
TOTAL DEPTH: 64.0 FT	HOLE DIAMETER:

PHOTOGRAPH



SECTION

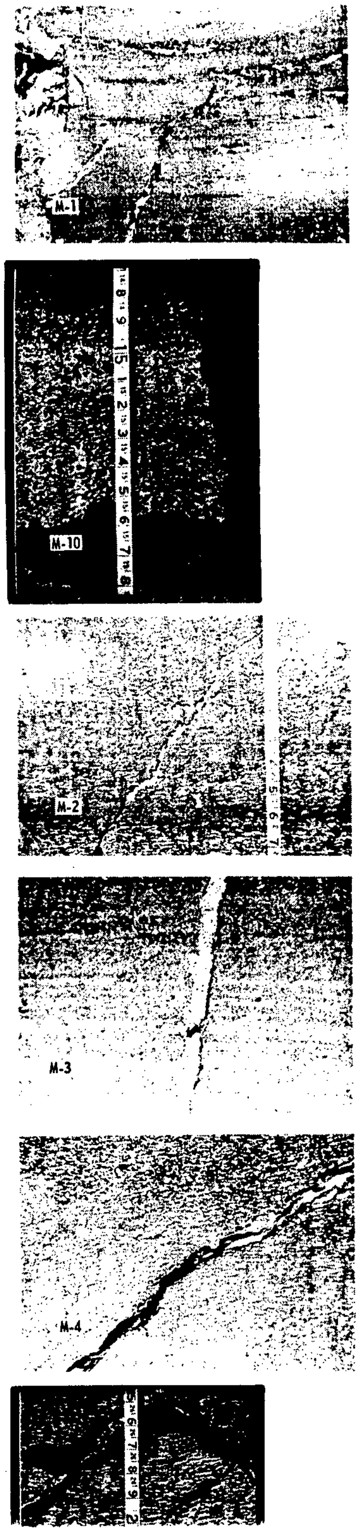


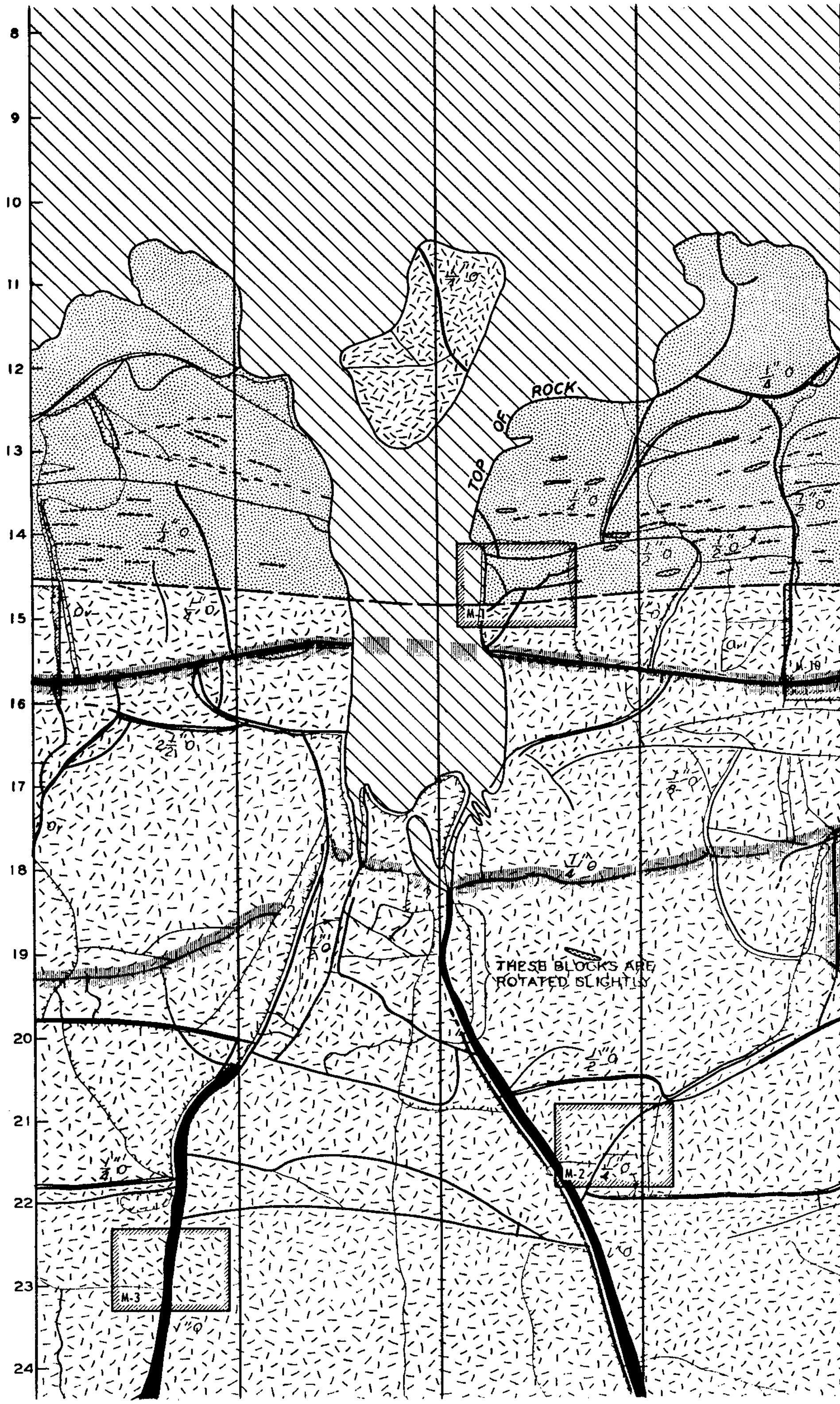
REMARKS

Tan, silty sand with caliche and fragments of vesicular basalt.

Loose soil containing basalt fragments. Many fragments dislodged from wall

①





Loose soil containing basalt fragments. Many fragments dislodged from wall.

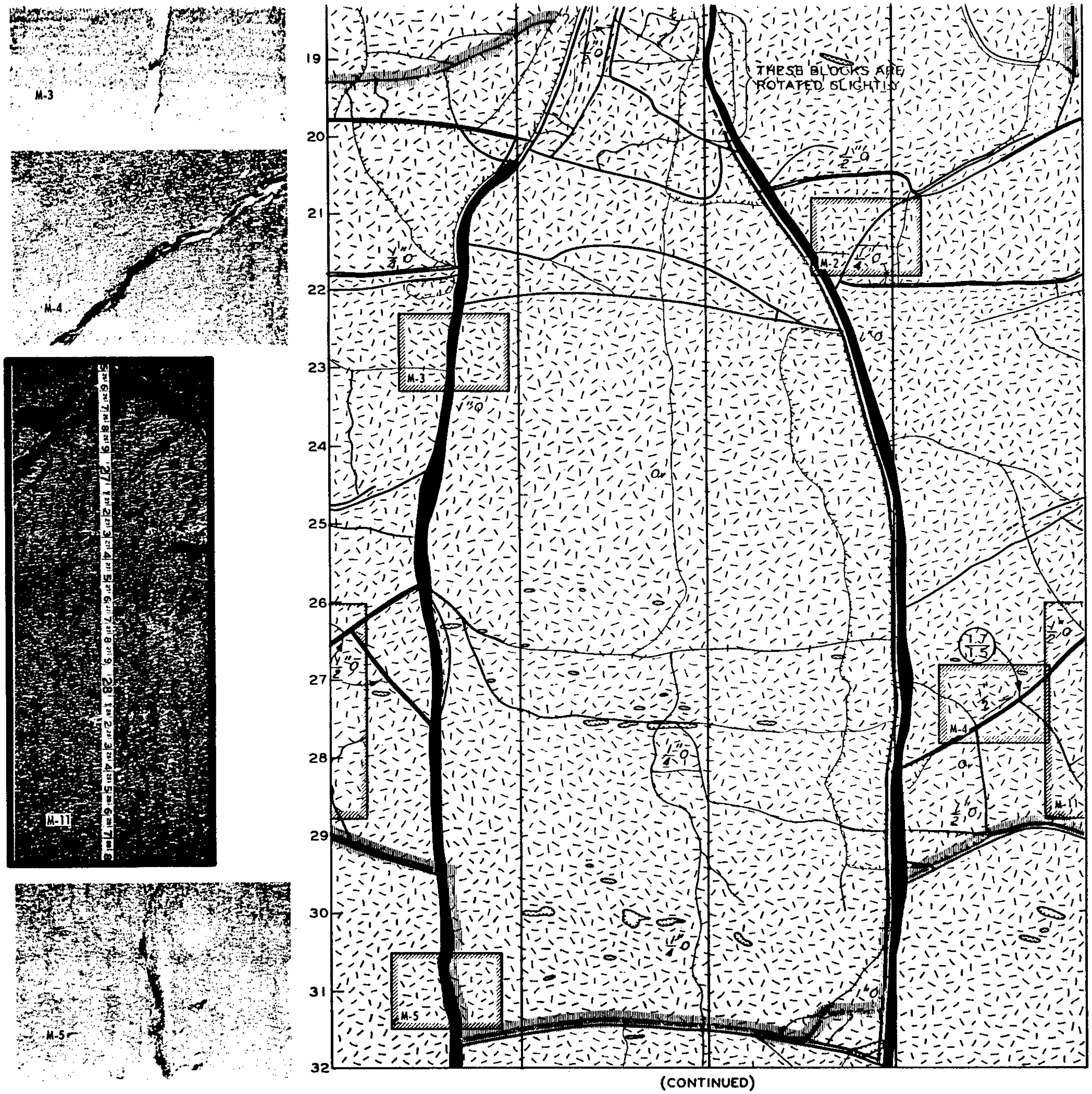
Vesicular basalt. 5 to 10% vesicles that range from 1/16 in. in length, to lines 3 in. in length and 1/8 in. in width, some banding of vesicles, with a dip to the south.

Lower wall of 2-in. fracture offset 2-1/2 in. S80°W relative to upper wall.

Lower wall of 1/4-in. fracture offset 1/2 in. S80°W relative to upper wall.

Vesicular basalt. 20 to 25% vesicles average 1/4 in. in length, with random orientation.

2



in length, with random orientation.

Increase in number of larger vesicles up to 7 in. in length and 2 in. in width.

Lower wall of 3/4 in. fracture offset 1 1/2 in. N 80°W relative to upper wall.

Figure B.13 Log of calyx Hole U18M.

3

(CONTINUED)

LOG OF CALYX HOLE

PROJECT: DUGOUT

ELEVATION: 5388.35

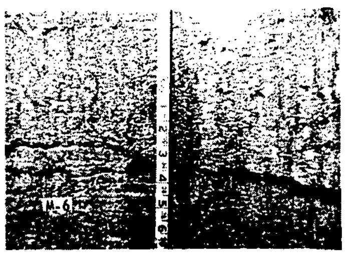
TOTAL DEPTH: 64.0 FT

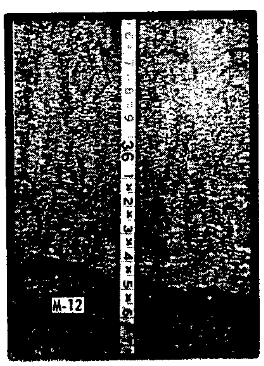
HOLE NO.: U 18 M

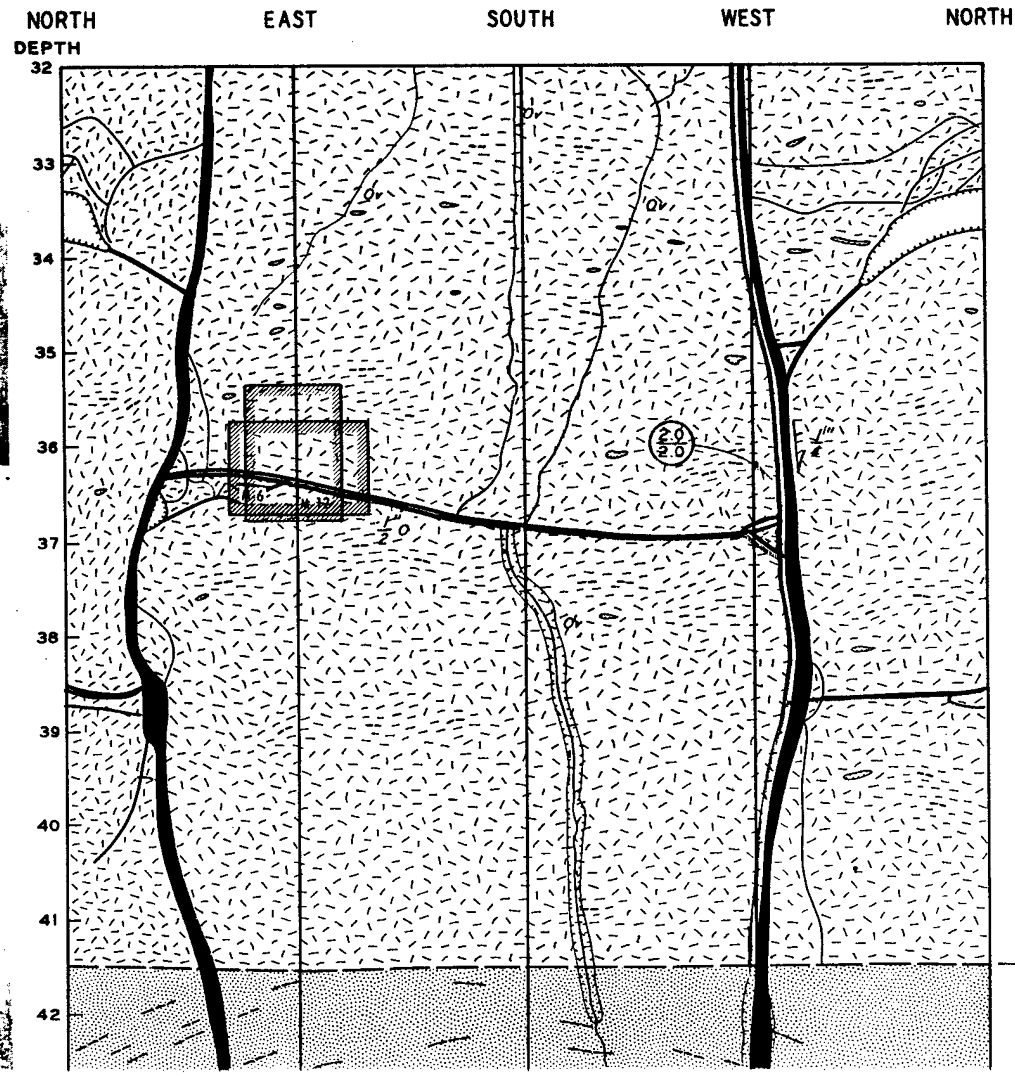
LOCATION: N853,290.00 E593,850.04

HOLE DIAMETER: 36 IN.

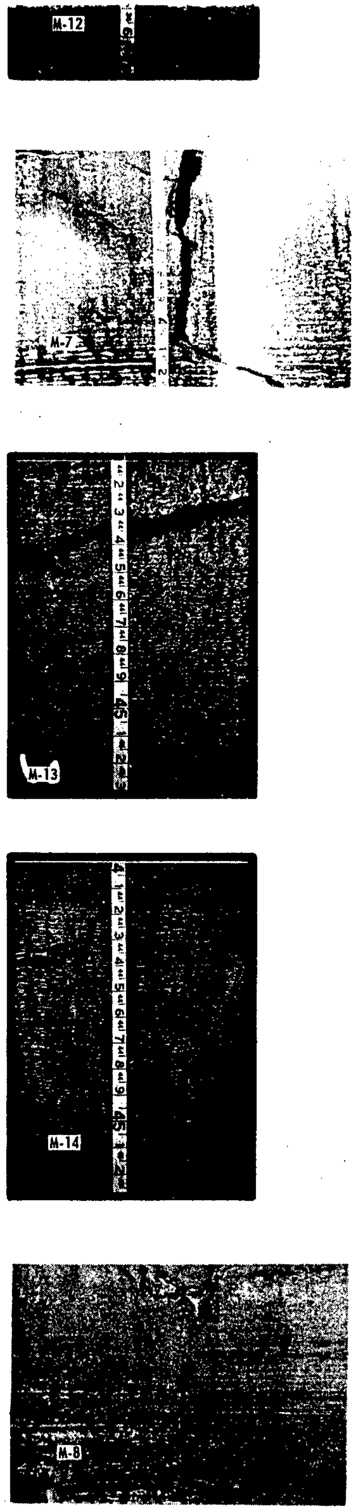
PHOTOGRAPH | SECTION | REMARKS

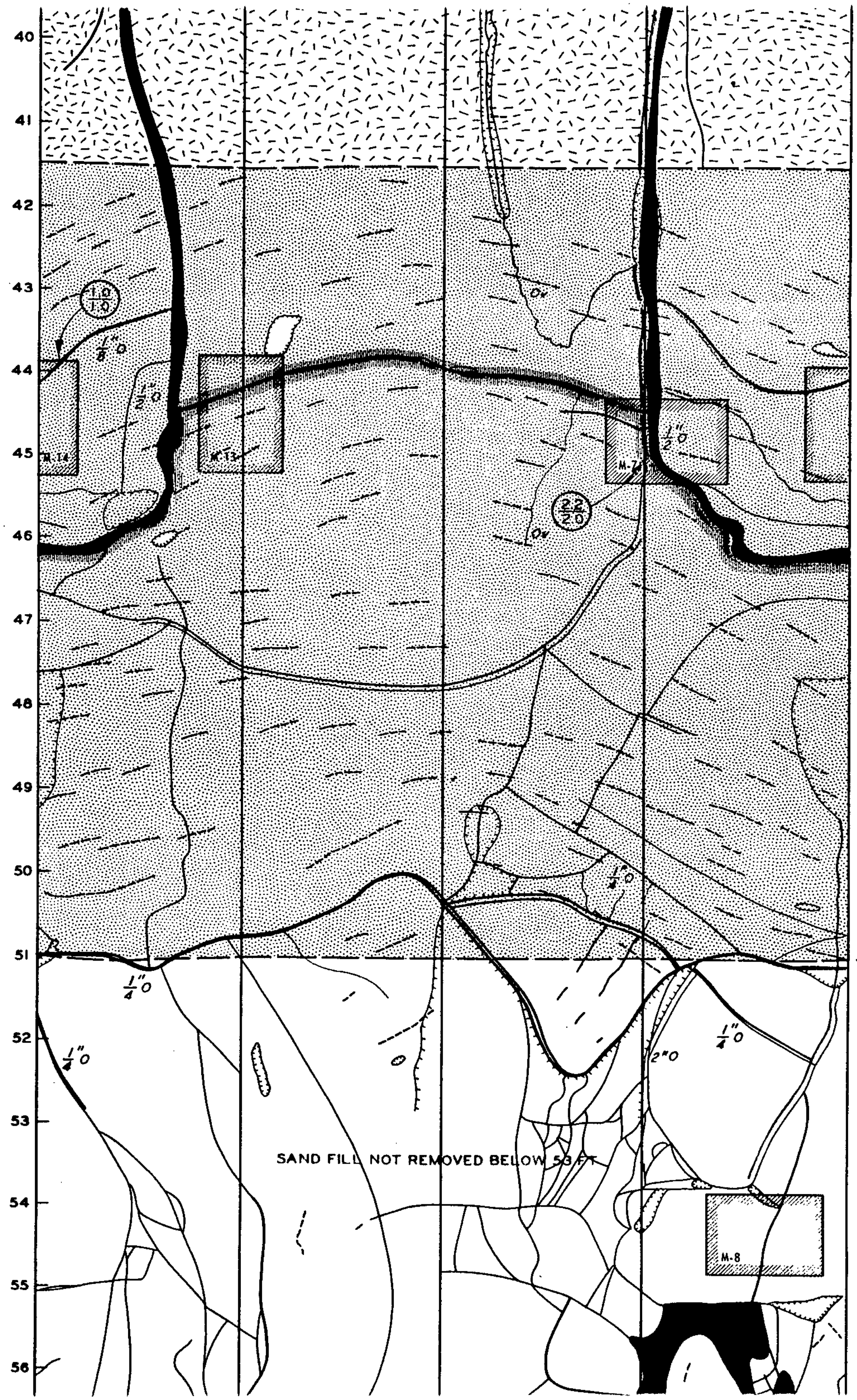






①





Lower wall of 3/8-in. fracture offset 1/2 in. N 80° W relative to upper wall.

Vesicular basalt. 0 to 5% vesicles up to 1 in. long and 1/8 in. wide, dip 20 to 30 degrees north.

2

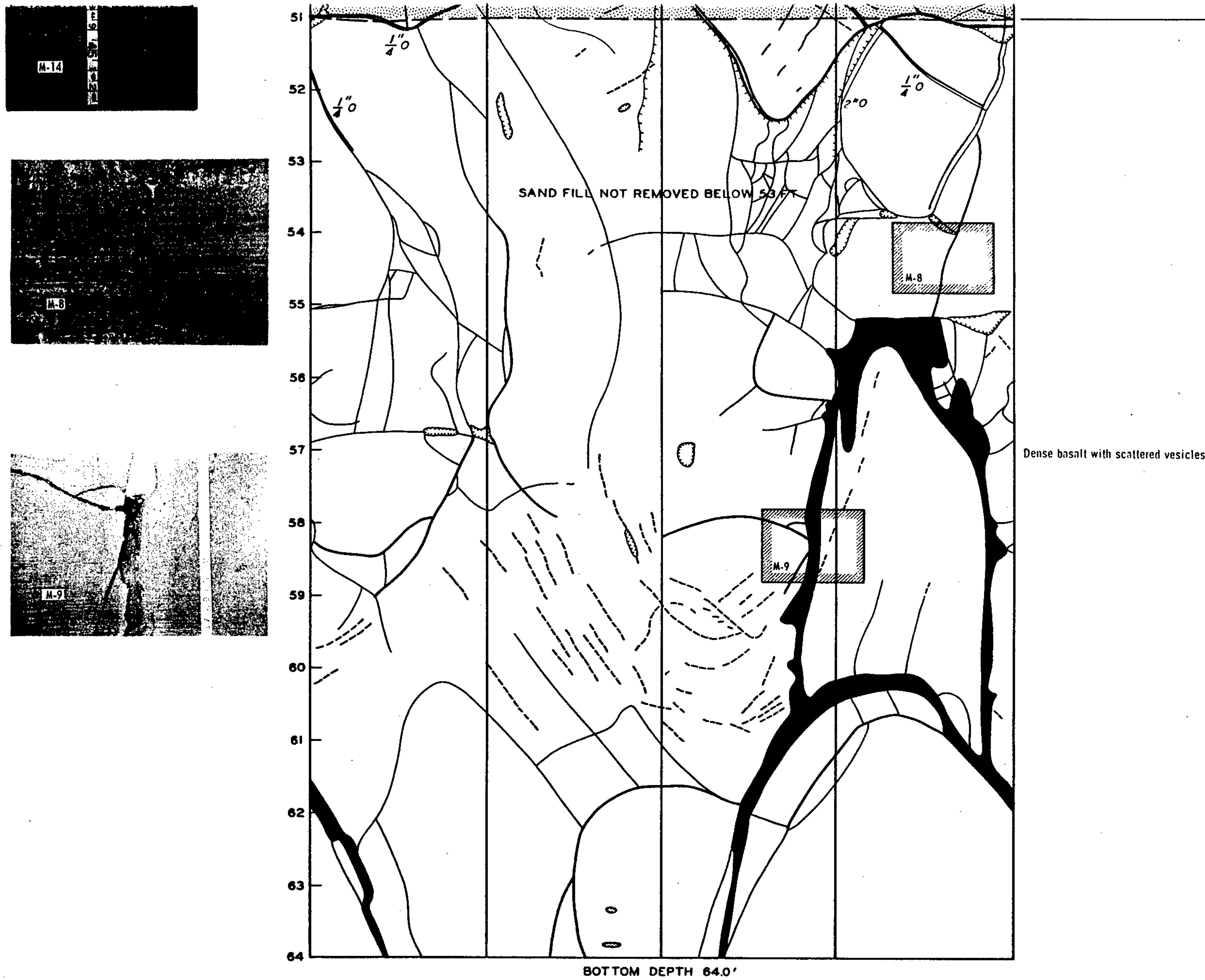


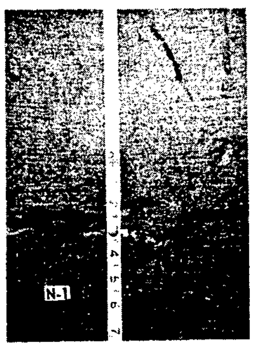
Figure B.14 Log of calyx Hole U18M (Continued).

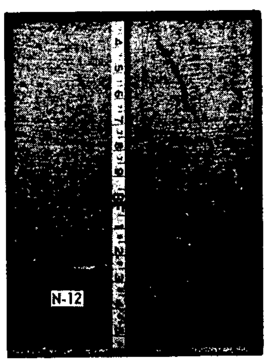
③

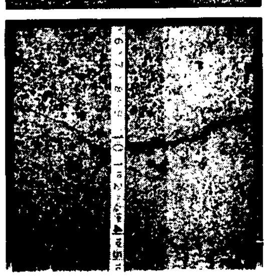
LOG OF CALYX HOLE

PROJECT: DUGOUT	HOLE NO.: U18N
ELEVATION: 5388.86	LOCATION: N853,290.00 E593,805.06
TOTAL DEPTH: 64.0 FT	HOLE DIAMETER: 36 IN.

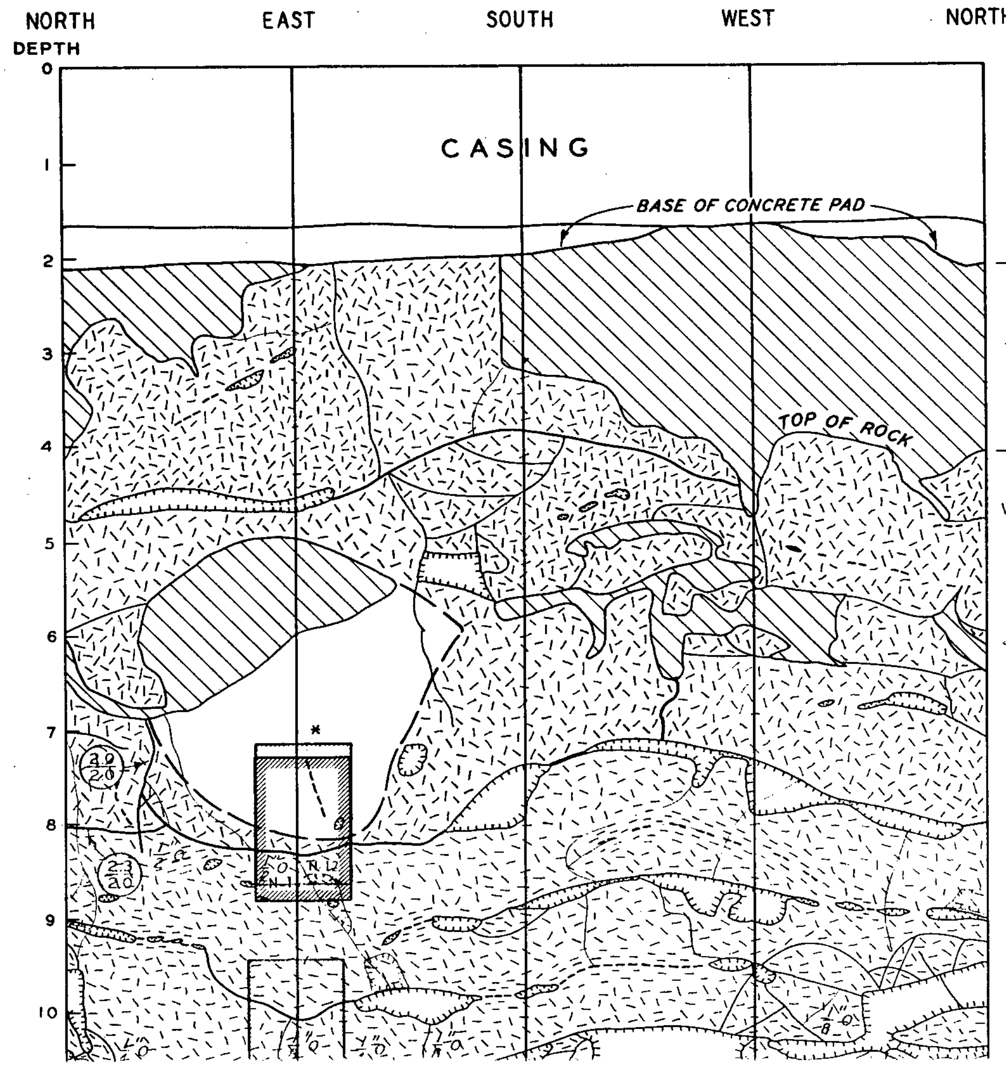
PHOTOGRAPH







SECTION

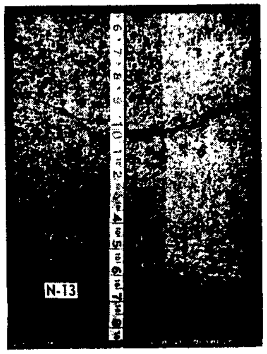


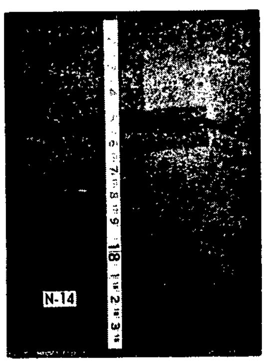
REMARKS

Tan, silty sand with caliche and fragments of vesicular basalt.

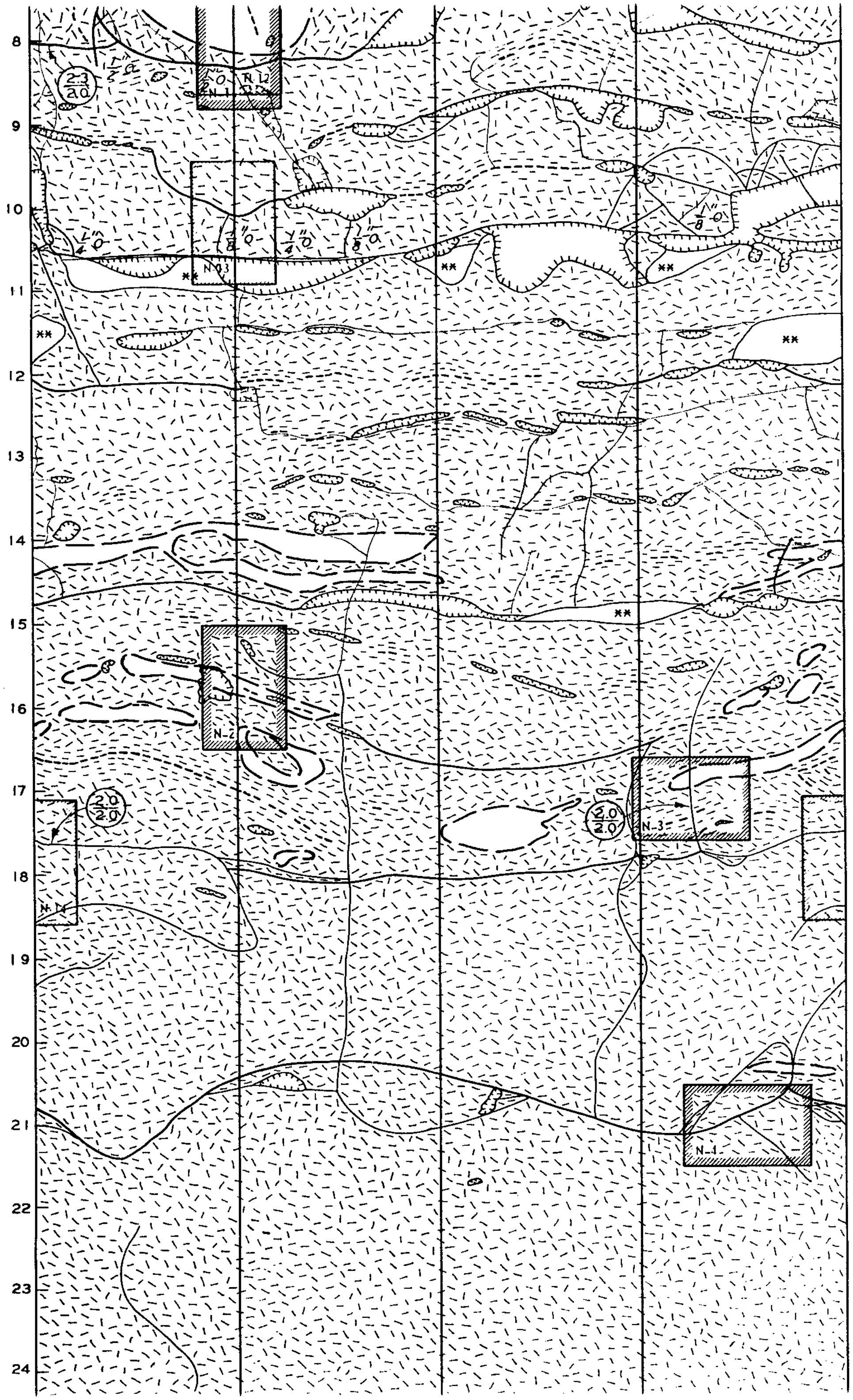
Vesicular basalt. 25 to 30% vesicles: smaller vesicles average 1/4 in. in length with random orientation; larger vesicles range up to 2 ft in length and 5 in. in width, and are horizontal.

* Dense basalt.





2



** Shattered rock

Dense basalt, numerous lenses.

25 to 30% vesicles, average 1/4 in. in length, many vesicles range up to 1 in. in length with random orientation.

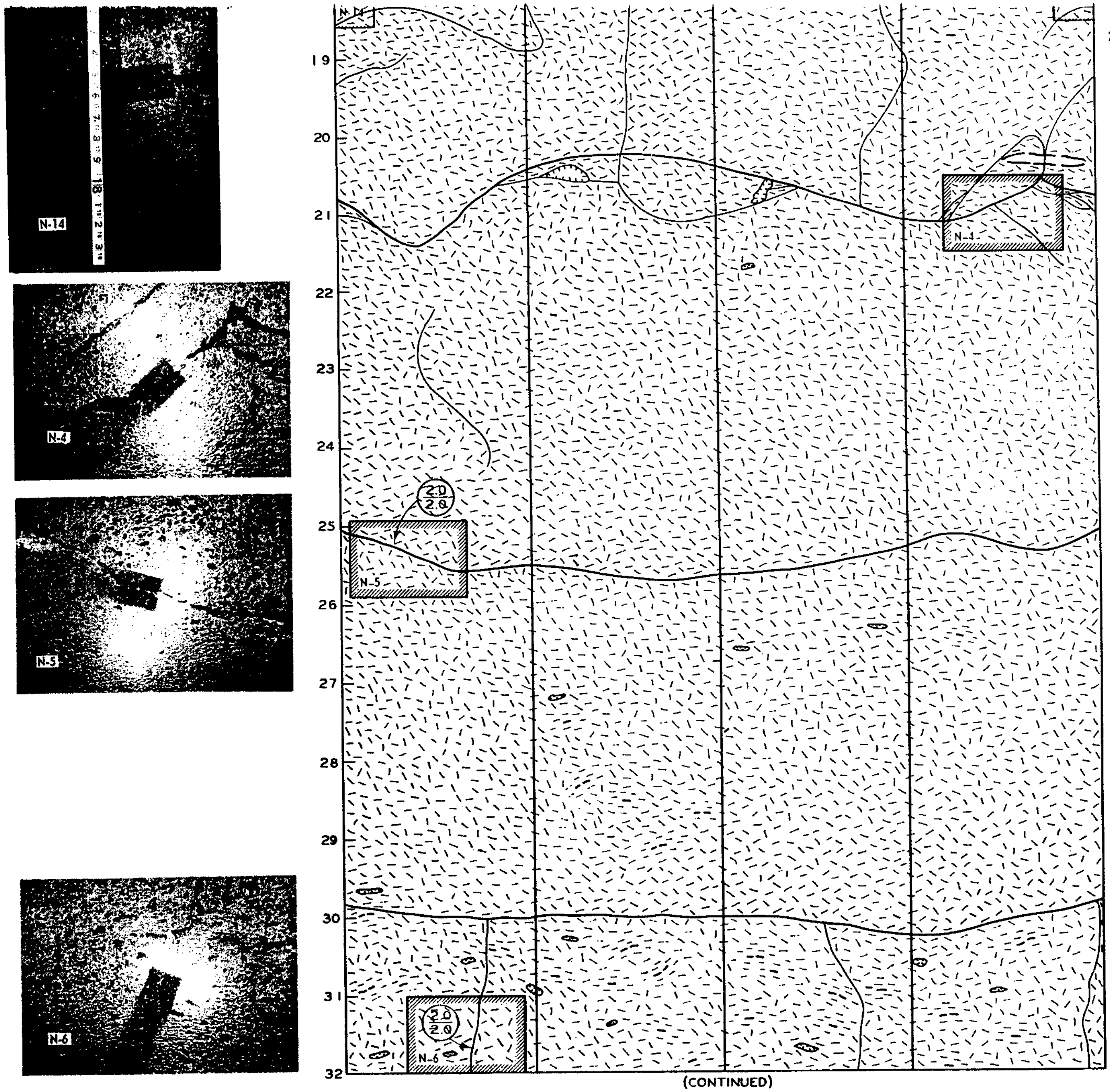


Figure B.15 Log of calyx Hole U18N.

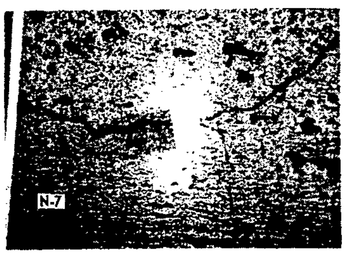
3

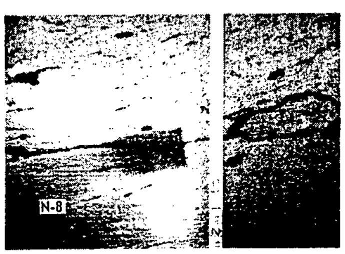
(CONTINUED)

LOG OF CALYX HOLE

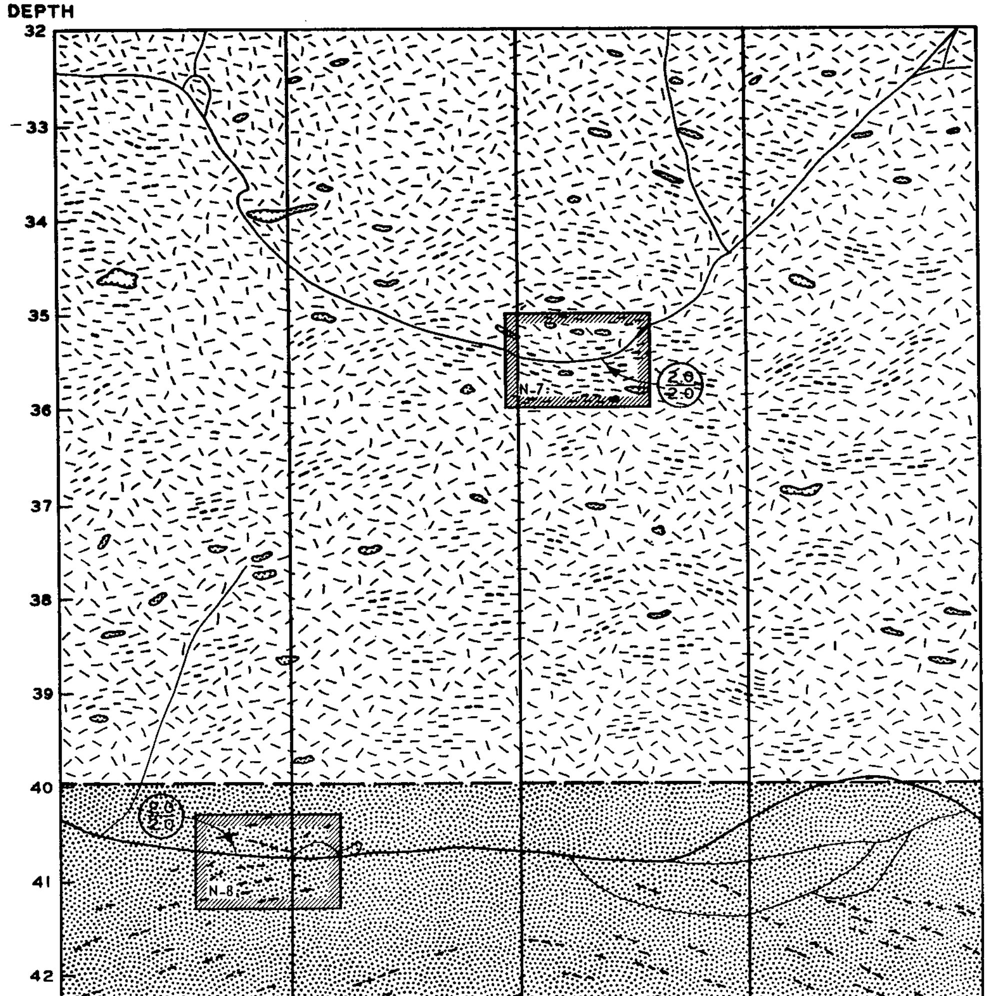
PROJECT: DUGOUT	HOLE NO.: U18N
ELEVATION: 5388.86	LOCATION: N853,290.00 E593,805.06
TOTAL DEPTH: 64.0 FT	HOLE DIAMETER: 36 IN.

PHOTOGRAPH

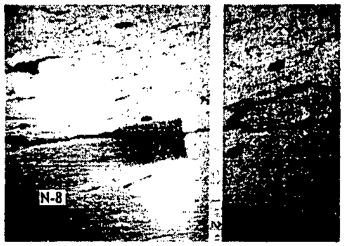


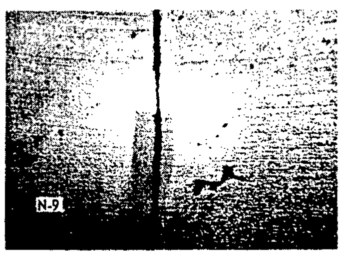


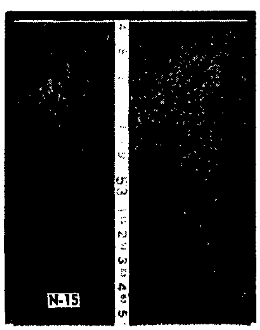
SECTION

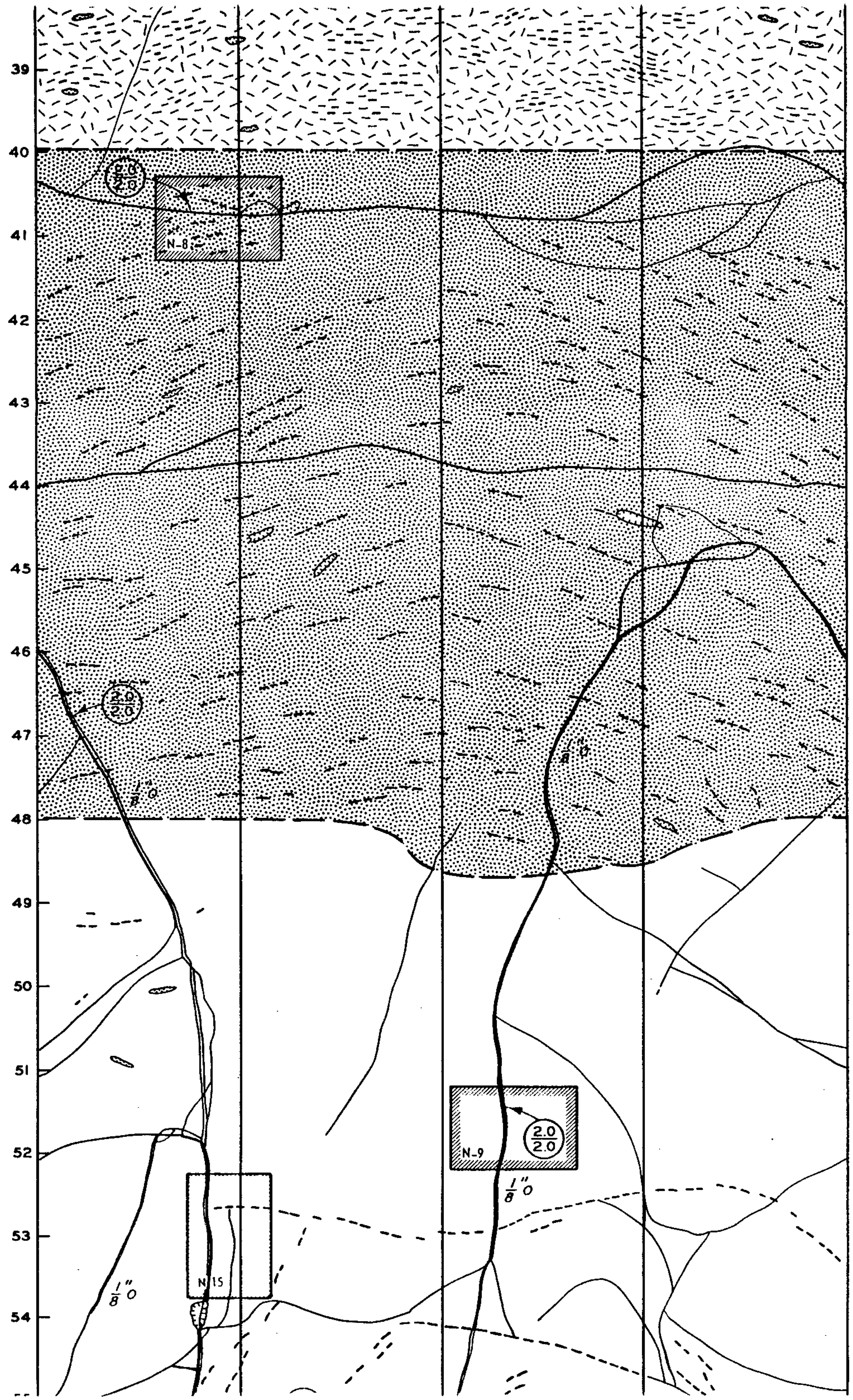


REMARKS









Vesicular basalt. 10% vesicles, in lines 1/8 in. in width and up to 1 ft in length. Dip 30 degrees north.

②

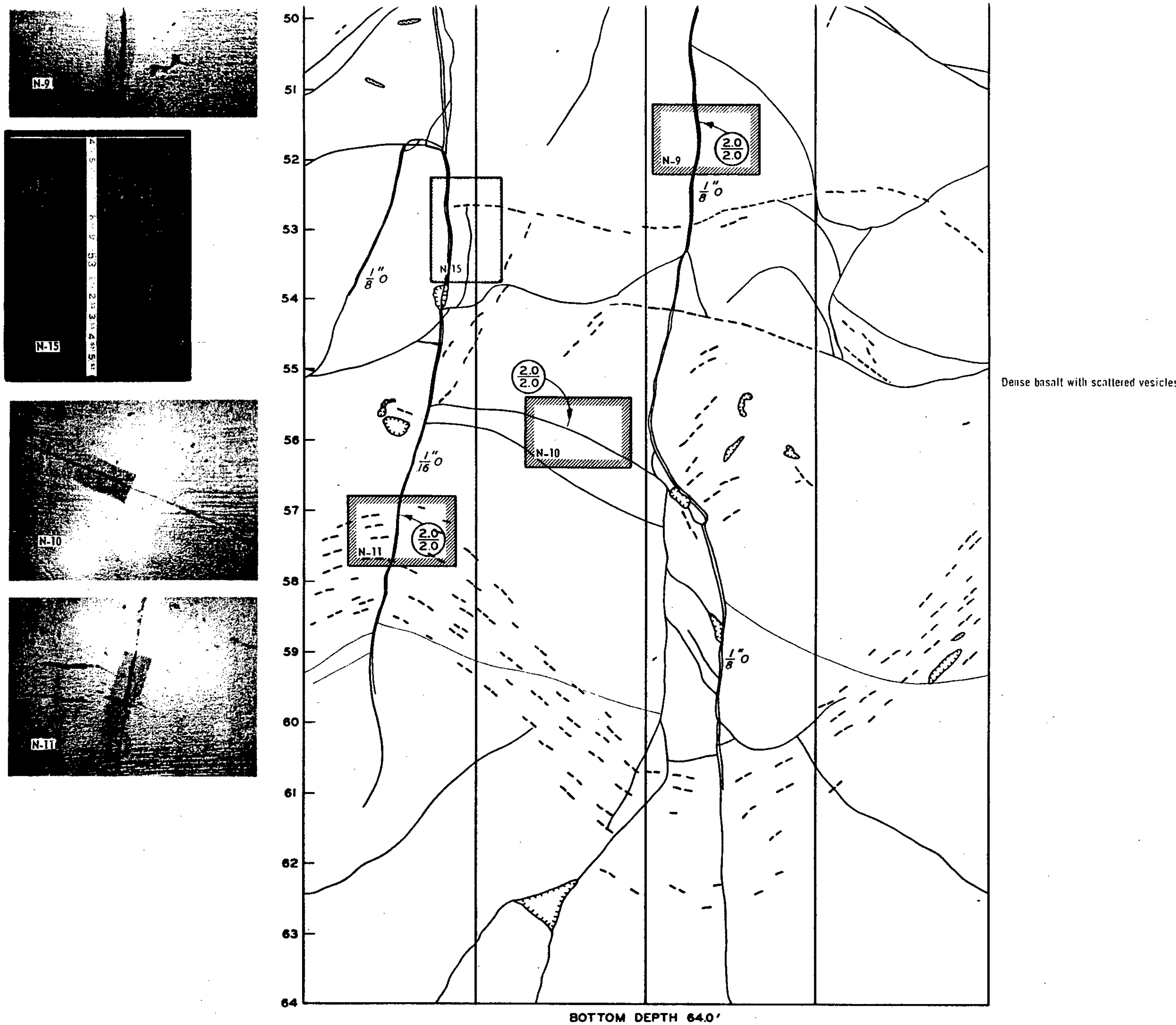


Figure B.16 Log of calyx Hole U18N (Continued).

3

LOG OF CALYX HOLE

PROJECT: DUGOUT

HOLE NO.: U18O

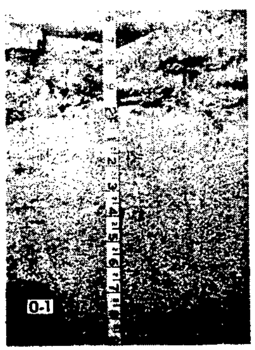
ELEVATION: 5389.05

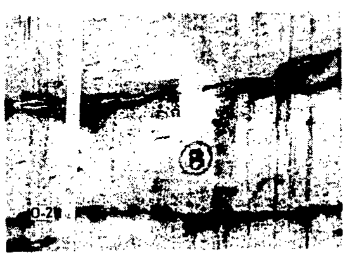
LOCATION: N853,290.00 E593,760.08

TOTAL DEPTH: 64.0 FT

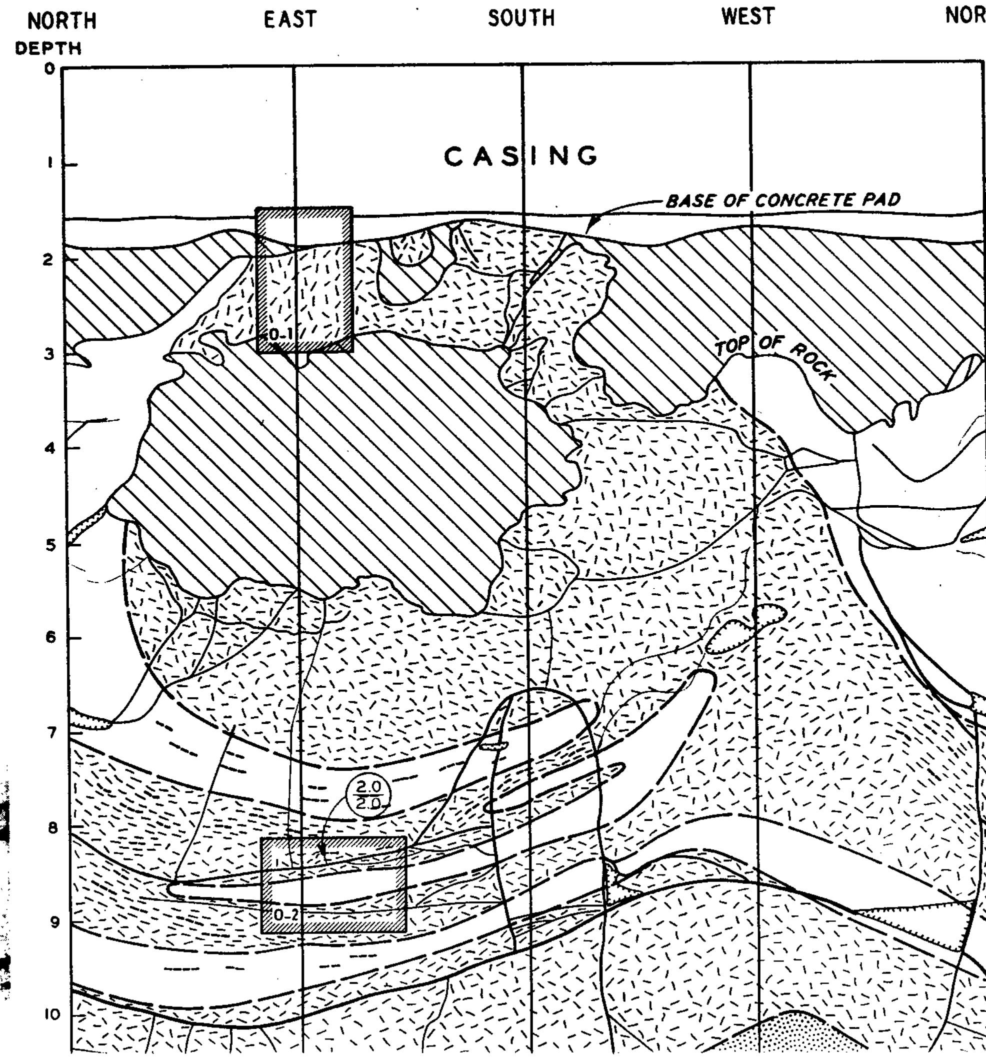
HOLE DIAMETER: 36 IN.

PHOTOGRAPH





SECTION



REMARKS

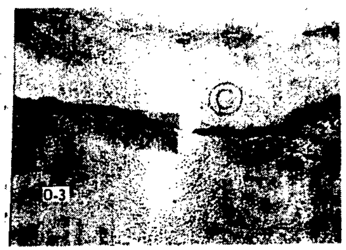
Tan, silty sand with caliche and fragments of vesicular basalt.

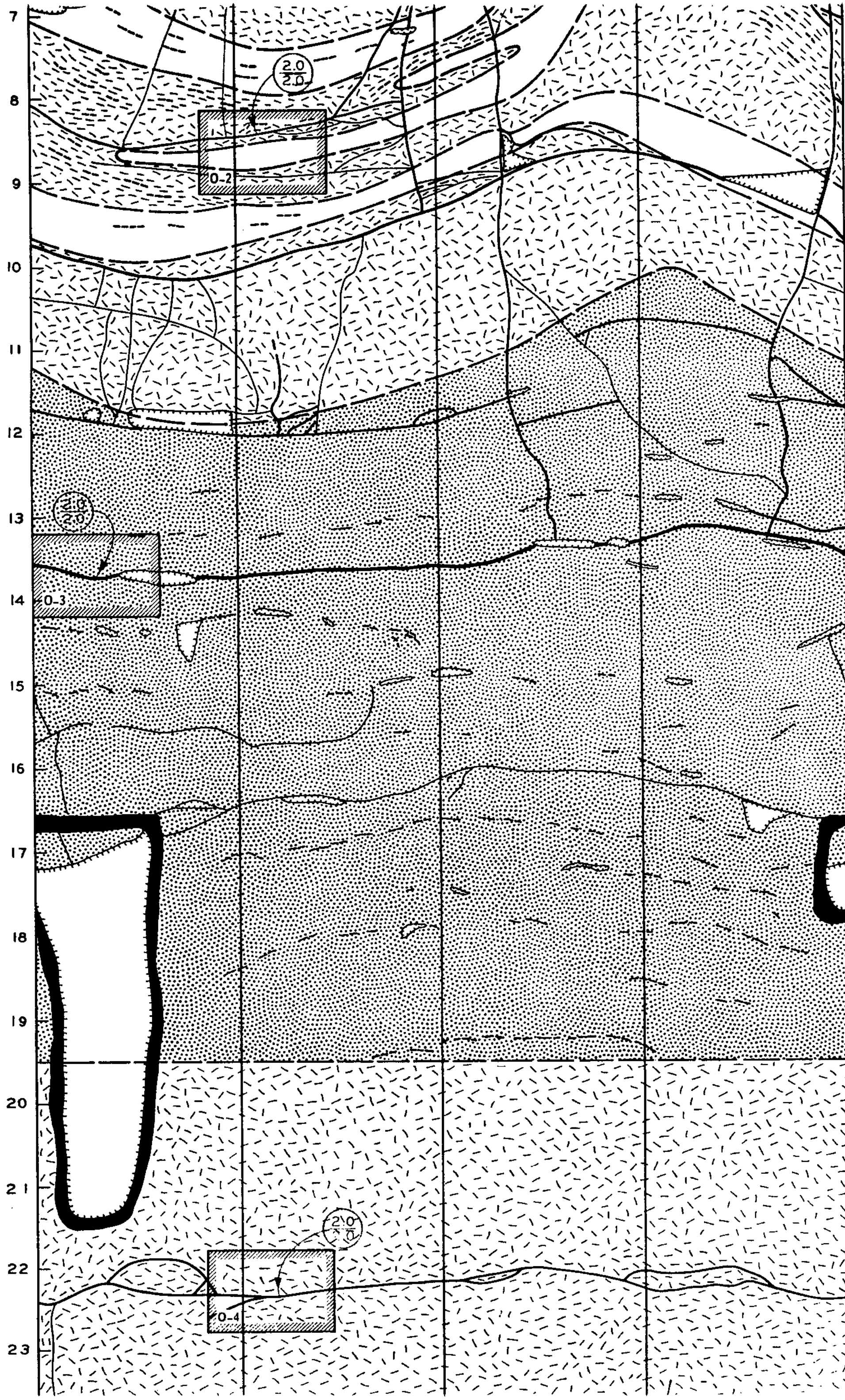
Vesicular basalt. 20 to 25% vesicles range from 1/16 to 1/2 in. in length, with random orientation.

Dense basalt, in thin lenses.

Vesicular basalt. 20% vesicles range from 1/16 to

①



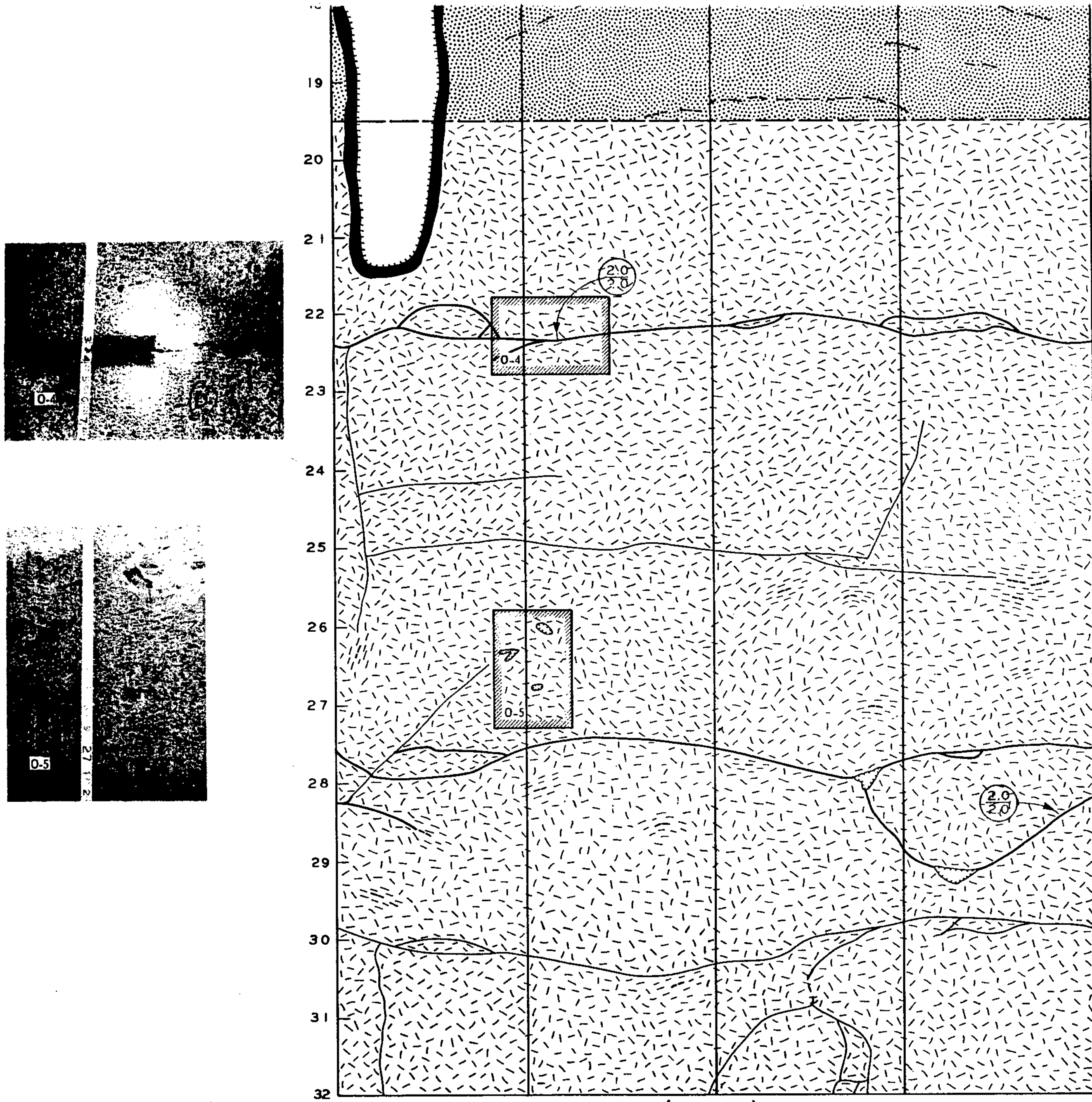


Dense basalt, in thin lenses.

Vesicular basalt. 20% vesicles range from 1/16 to 2 in. in length, with random orientation.

Vesicular basalt. 15 to 20% vesicles: smaller vesicles average 1/4 in. in length with random orientation; large vesicles range up to 1 ft in length and 1 in. in width, and are horizontal.

②



Vesicular basalt. 20 to 25% vesicles average 1/4 in. in length, range from 1/16 to 1 in. in length and up to 1/4 in. in width. Few vesicles range up to 2 in. in length and 1/2 in. in width, with random orientation.

(CONTINUED)

Figure B.17 Log of calyx Hole U180.

3

(CONTINUED)

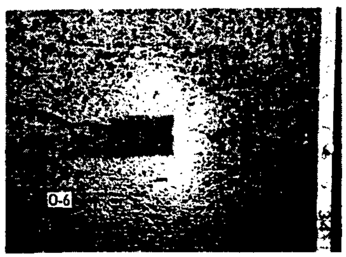
LOG OF CALYX HOLE

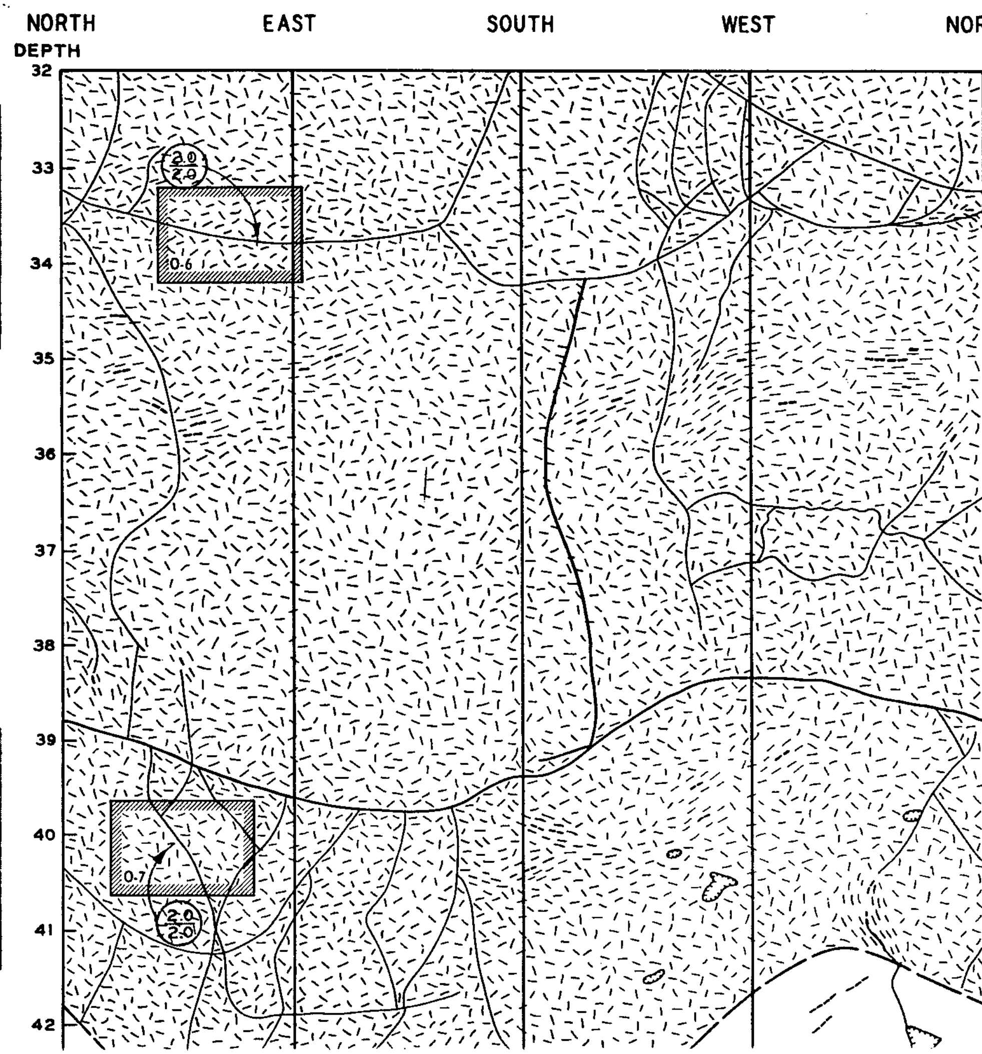
PROJECT: DUGOUT	HOLE NO.: U18O
ELEVATION: 5389.05	LOCATION: N853,290.00 E593,760.08
TOTAL DEPTH: 64.0 FT	HOLE DIAMETER: 36 IN.

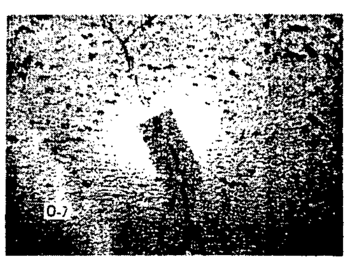
PHOTOGRAPH

SECTION

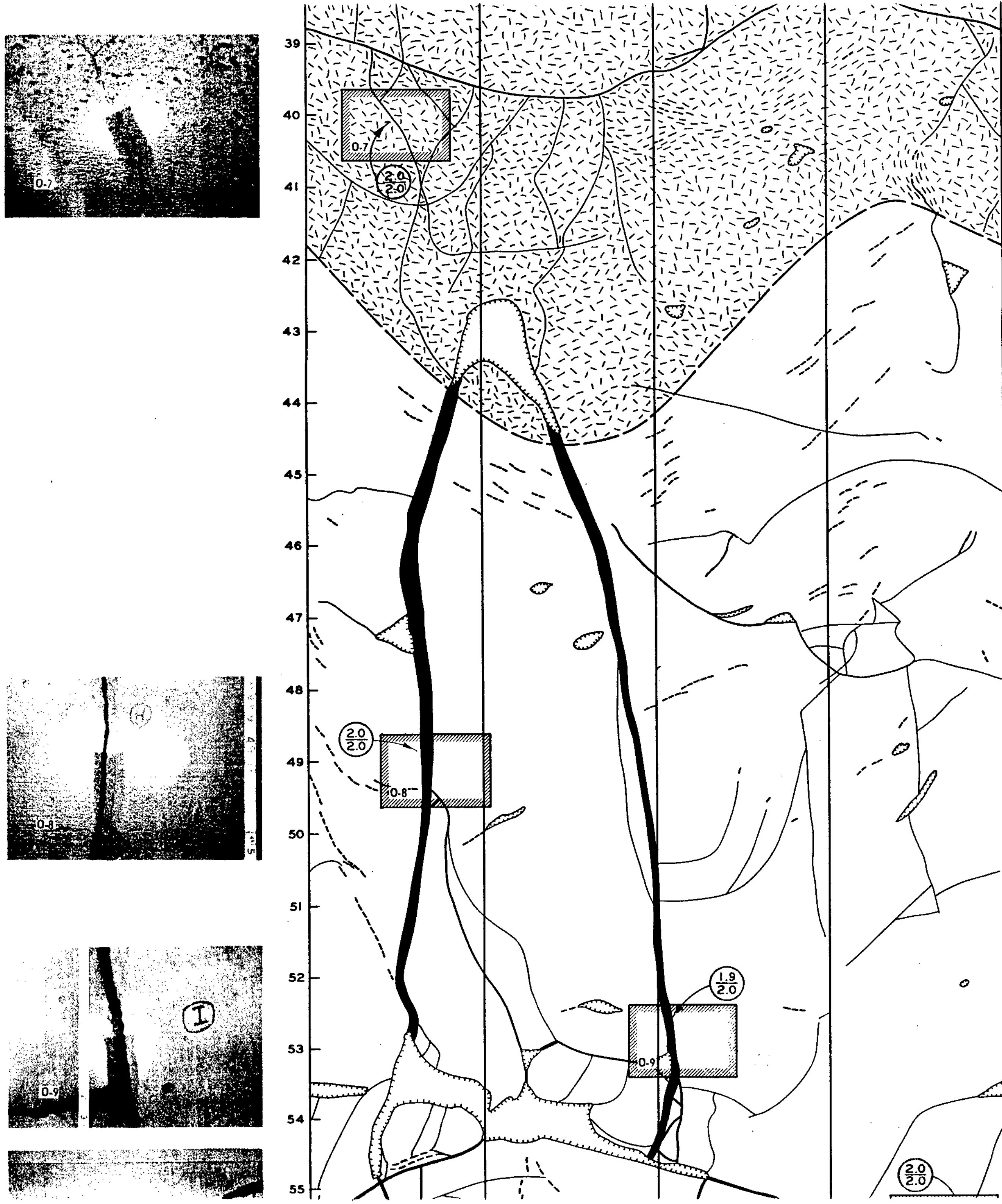
REMARKS





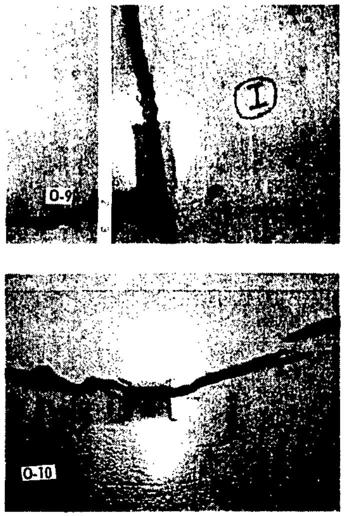


(1)



Dense basalt with widely scattered vesicles.

2



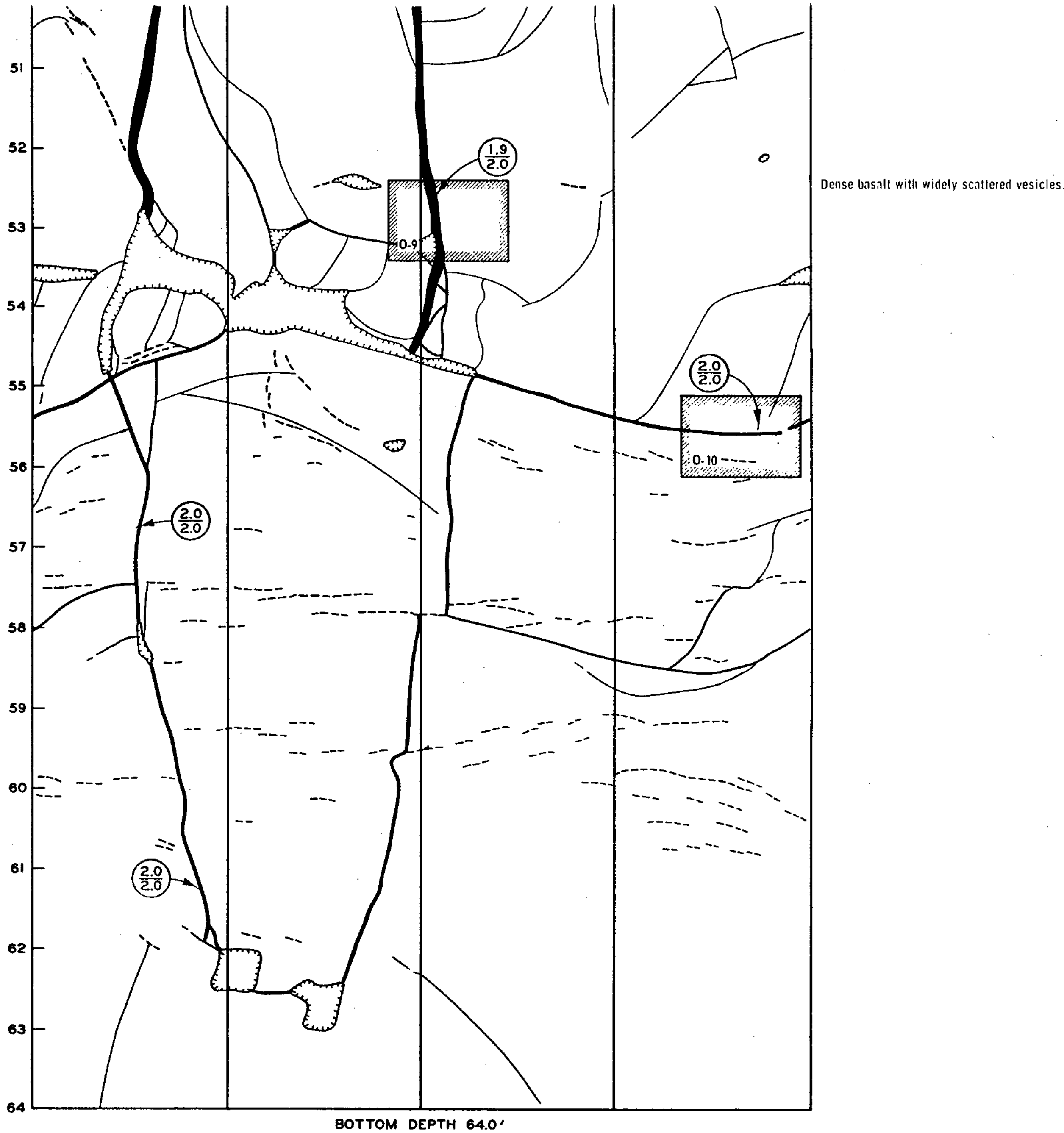


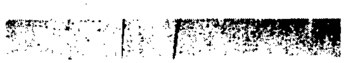
Figure B.18 Log of calyx Hole U180 (Continued).

3

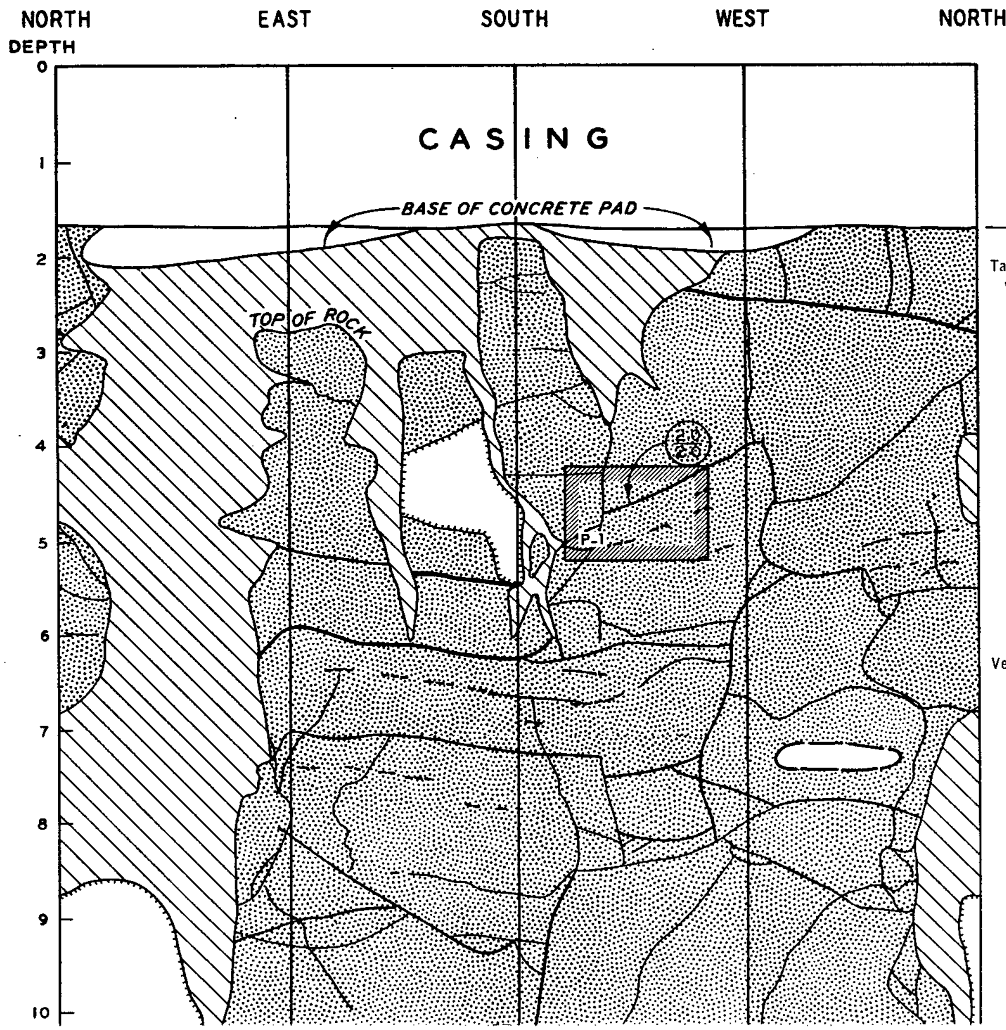
LOG OF CALYX HOLE

PROJECT: DUGOUT	HOLE NO.: U 18 P
ELEVATION: 5389.58	LOCATION: N853,290.00 E593,715.10
TOTAL DEPTH: 64.0 FT	HOLE DIAMETER: 36 IN.

PHOTOGRAPH



SECTION

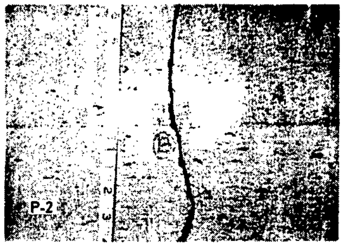


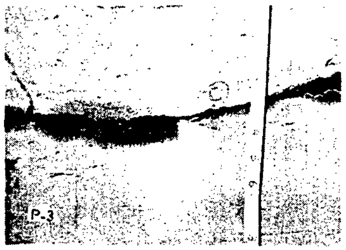
REMARKS

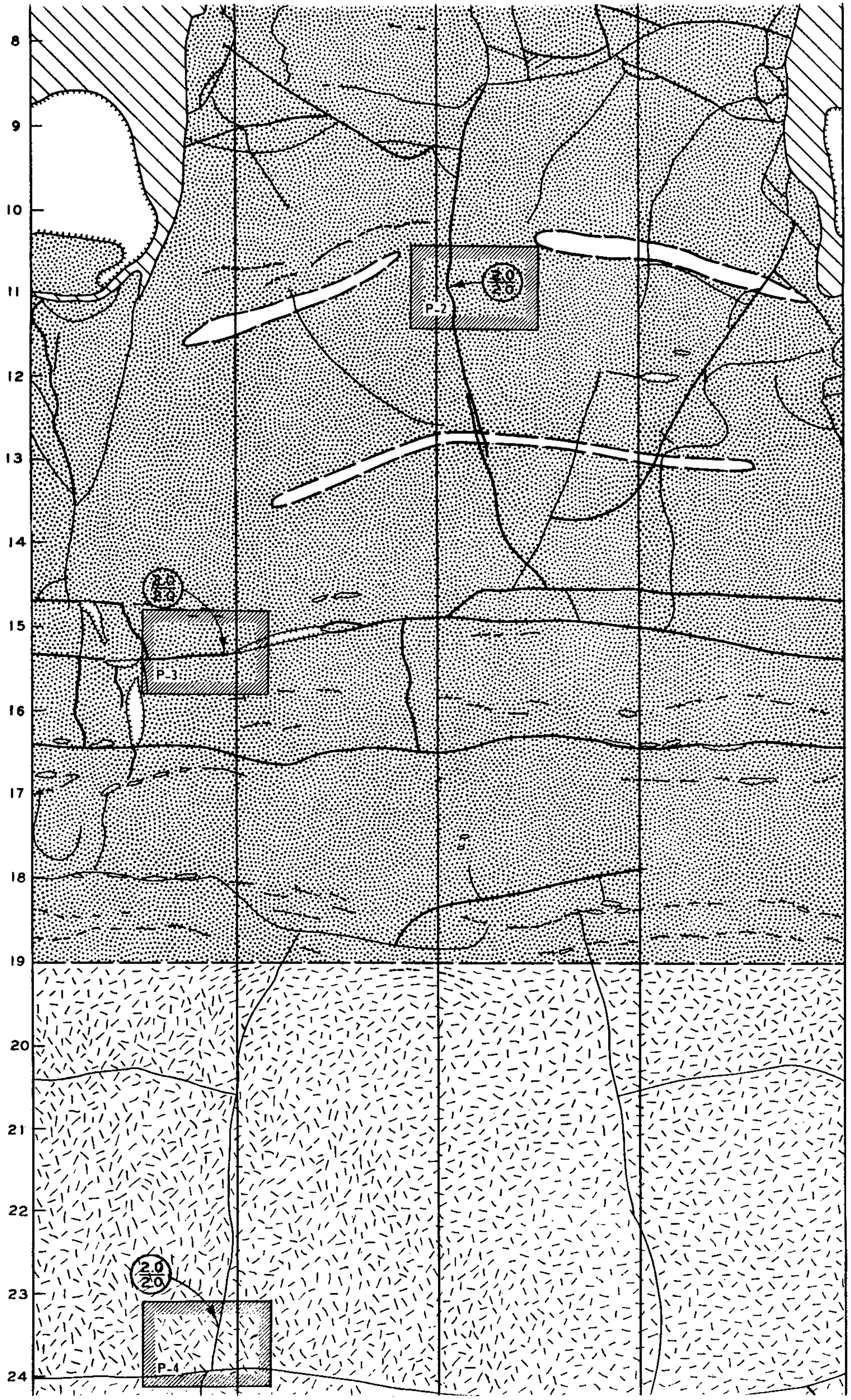
Tan, silty sand with caliche and fragments of vesicular basalt.

Vesicular basalt. 15 to 20% vesicles, range from 1/16 to 1/2 in. in width, with random orientation.

1







15% vesicles, range from 1/16 to 4 in. in length, small vesicles average 1/4 in. in length, and are horizontal.

(2)

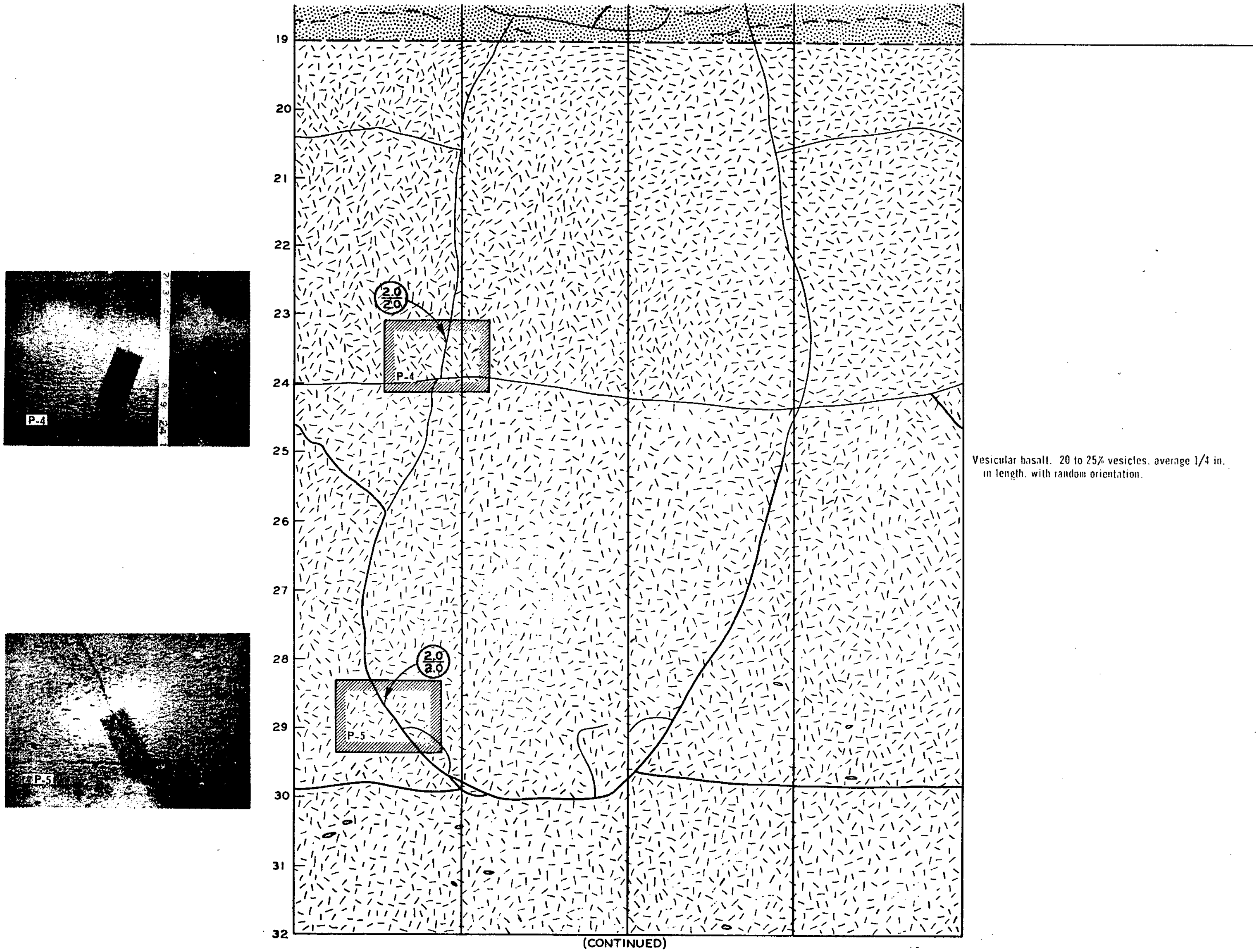


Figure B.19 Log of calyx Hole U18P.

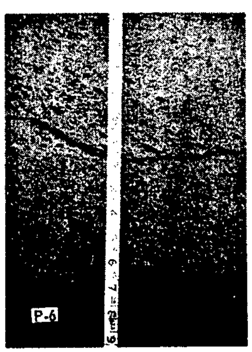
3

(CONTINUED)

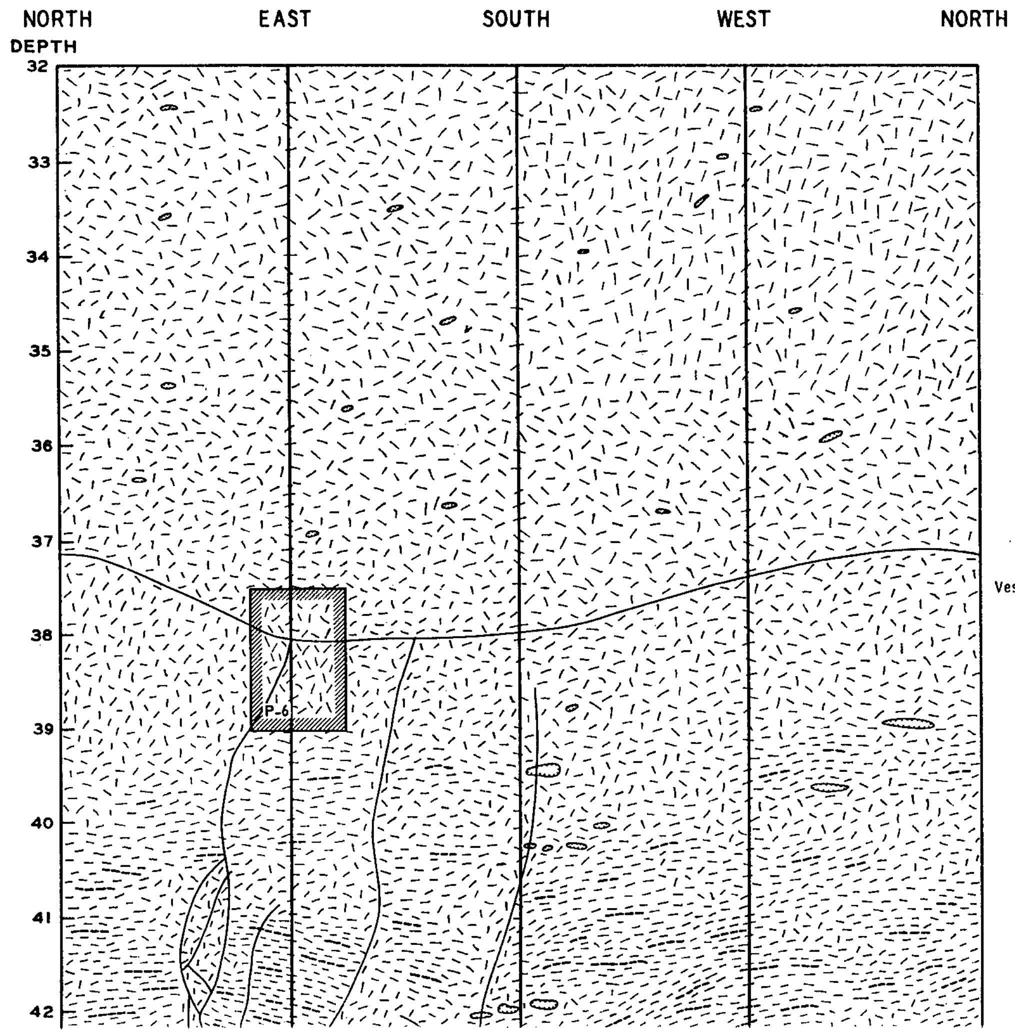
LOG OF CALYX HOLE

PROJECT: DUGOUT	HOLE NO.: U18P
ELEVATION: 5389.58	LOCATION: N853,290.00 E593,715.10
TOTAL DEPTH: 64.0 FT	HOLE DIAMETER: 36 IN.

PHOTOGRAPH



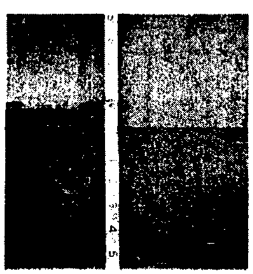
SECTION

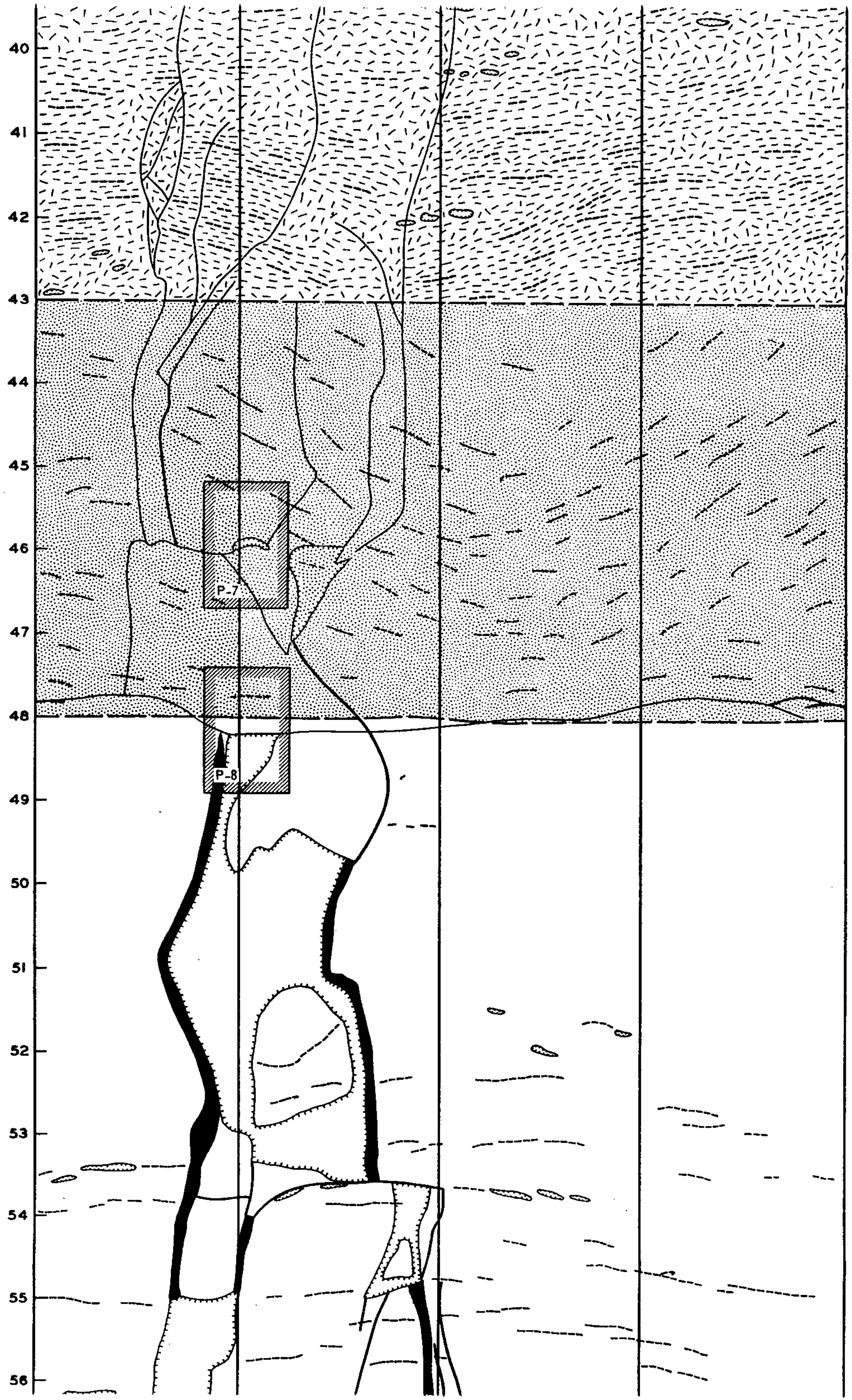


REMARKS

Vesicles dipping 20 degrees to the south.

1





Vesicular basalt. 5% vesicles, and are in layers 1 to 3 in. apart, dipping 35 degrees southwest.

Dense basalt with scattered vesicles.

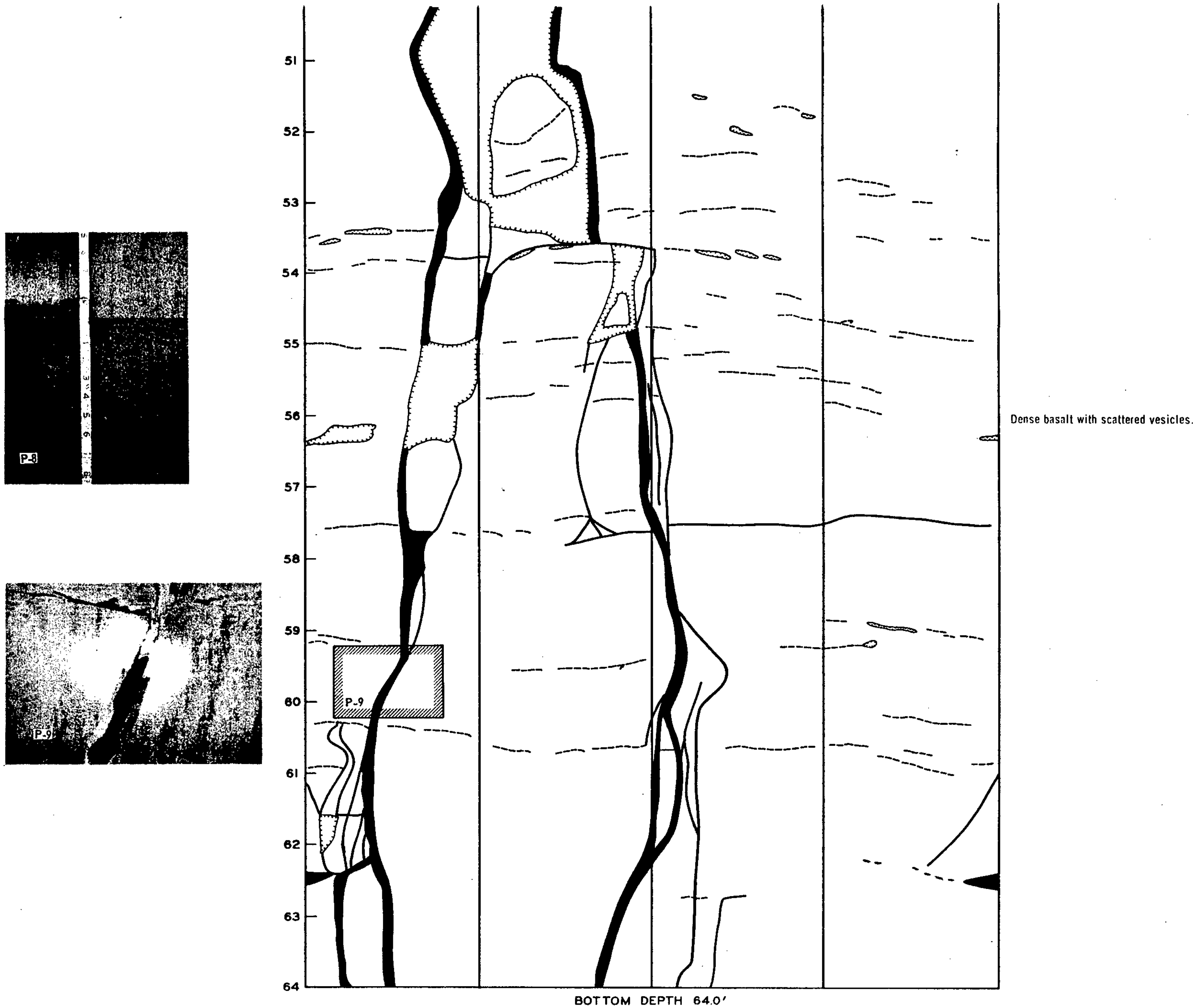


Figure B.20 Log of calyx Hole U18P (Continued).

3

APPENDIX C

POSTSHOT BORING LOGS

(See legend for Appendix A.)

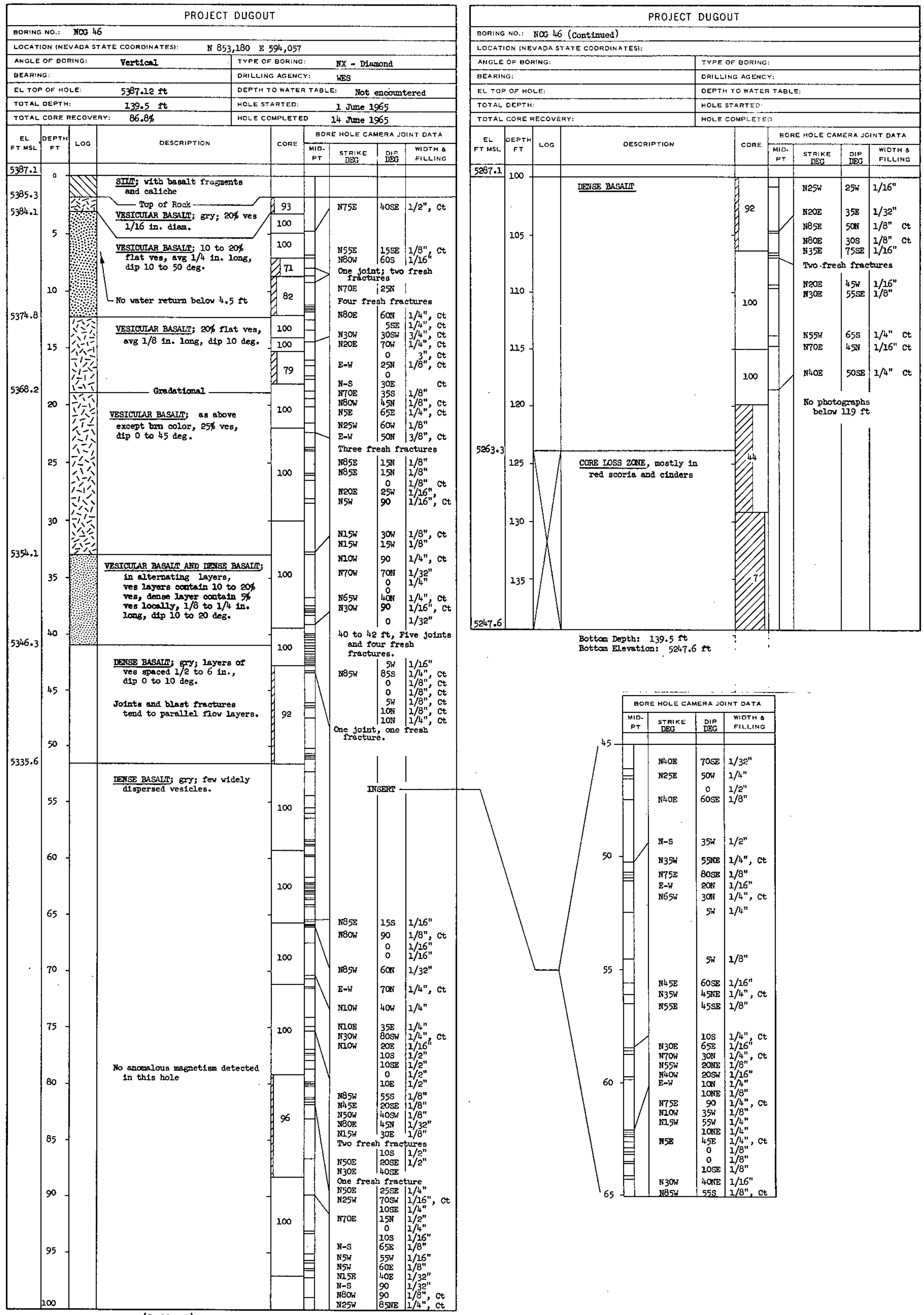


Figure C.1 Log of core Boring NCG 46.

PROJECT DUGOUT

BORING NO.:	NCG 47		
LOCATION (NEVADA STATE COORDINATES):	N 853,177 E 594,056		
ANGLE OF BORING:	30 deg from Vertical	TYPE OF BORING:	NX - Diamond
BEARING:	South	DRILLING AGENCY:	WES
EL TOP OF HOLE:	5387.20 ft MSL	DEPTH TO WATER TABLE:	Not encountered
TOTAL DEPTH:	115.9 ft	HOLE STARTED:	8 June 1965
TOTAL CORE RECOVERY:	95.1%	HOLE COMPLETED	11 June 1965

EL FT MSL	DEPTH FT	DESCRIPTION
5387.2	0	SILT; with caliche and basalt fragments
5385.0		—— Top of Rock ——
		VESICULAR BASALT; gry; 20 to 25% ves, mostly flat and dipping 30 to 50 deg, avg 1/8 in. long
		No water return below 5.0 ft
5364.2		VESICULAR BASALT; as above except brn
5354.8		—— Gradational ——
		VESICULAR BASALT; as above except gry
5347.8	40	VESICULAR BASALT AND DENSE BASALT; in alternating layers, ves layers contain 15% ves, dense layers contain 5% ves concentrated in layers spaced 1/2 to 2 in. apart, ves avg 1/4 in. long, dip 0 to 45 deg.
		Fractures parallel flow layers
5334.4		DENSE BASALT; gry; layers of ves spaced 1/2 to 1-1/2 in., dip 10 to 20 deg
5324.7		DENSE BASALT; gry; few widely dispersed ves
		78.8 to 84.8 ft, anomalous magnetism evident by swing of compass needle 90 deg; no other anomaly in this hole.
	100	

CORE (%), top to bottom: 100, 96, 100, 84, 88, 100, 59, 100, 91, 100, 100, 100, 100, 100, 100, 100, 91, 100, 100

BORE HOLE CAMERA JOINT DATA

STRIKE DEG	DIP DEG	WIDTH & FILLING
N62W	63S	1/8", Ct
E-W	30N	1/8", Ct
N45W	67SW	1/2", Ct
N75E	15S	1/4", Ct
N80E	74N	1/4", Ct
N70W	52S	1/2", Ct
N75E	48N	1/4", Ct
N65E	32S	1", Ct
N83W	50S	1", Ct
N65W	43N	1/4", Ct
N35W	13NE	1/8"
N67E	62S	>1", Ct
N5E	89E	1/16"
N67E	62S	1/4", Ct
N5W	40W	1/4", Ct
N38W	13W	1/8", Ct
E-W	30N	1/8", Ct
N75W	70N	1/8", Ct
N78E	20S	1/16"
E-W	80N	1/4", Ct
N62W	16S	1/4", Ct
N9E	25W	1/8"
N53W	18SW	1/4", Ct
INSERT		
N65E	10N	1/2", Ct
N34E	75NW	1/16"
N7E	5W	1/4", Ct
N45W	90	1/4", Ct
N70E	24N	1/16"
N5E	10W	1/4", Ct
N10E	13W	1/4", Ct
N3W	65W	1/16"
One fresh fracture		
N33W	44SW	1/8"
E-W	10N	1/4", Ct
E-W	10N	1/8"
E-W	10N	1/16"
E-W	30N	1/32"
N-S	35W	1/8", Ct
One fresh fracture		
	0	1/4"
N30W	31E	1/8", Ct
N37W	59NE	1/8", Ct
N70E	82N	1/8", Ct
N10W	22W	3/16"
N45W	50NE	1/16"
N63W	16S	1/16"
N32E	15SE	1/8"
N5W	5E	1/16"
N40E	25SE	1/16"
N25W	27E	1/8"
N30E	33E	1/8"
N25E	42E	1/8"
N4E	59E	1/8"
N12W	22W	1/4", Ct
N25W	83W	1/8", Ct
N10W	78W	1/4", Ct
N47E	30NW	1/4", Ct
N35W	37NE	1/8"
N15E	30W	1/32"
N54E	11S	1/16"
N54E	11S	1/16"
N45W	35NE	1/8"
N16W	34W	1/4"
N41W	85NE	1/4", Ct
N42E	47SE	1/8"
N5E	39E	1/8"
N33E	57NW	1/8", Ct
N80E	20S	1/4"

(Continued)

PROJECT DUGOUT

BORING NO.:	NCG 47 (Continued)		
LOCATION (NEVADA STATE COORDINATES):			
ANGLE OF BORING:		TYPE OF BORING:	
BEARING:		DRILLING AGENCY:	
EL TOP OF HOLE:		DEPTH TO WATER TABLE:	
TOTAL DEPTH:		HOLE STARTED:	
TOTAL CORE RECOVERY:		HOLE COMPLETED	

EL FT MSL	DEPTH FT	DESCRIPTION
5287.2	100	DENSE BASALT
	105	
	110	
5271.3	115	

CORE (%), top to bottom: 100, 100, 100

BORE HOLE CAMERA JOINT DATA

STRIKE DEG	DIP DEG	WIDTH & FILLING
E-W	30N	1/8"
N20E	60W	1/8", Ct
N45W	63E	1/8", Ct
N5E	10W	1/16"
N82E	5S	1/8"
N30W	60E	1/8"
N-S	35W	1/32", Ct
N-S	55W	1/8", Ct
N30E	54W	1/8", Ct
N54W	78N	1/4", Ct
E-W	5S	1/32"
N31E	67W	1/16", Ct
N14W	12E	1/8", Ct

Bottom Depth: 115.9 ft
Bottom Elevation: 5271.3 ft

BORE HOLE CAMERA JOINT DATA (insert, depth 20 to 35 ft)

STRIKE DEG	DIP DEG	WIDTH & FILLING
N17W	52W	1/8", Ct
N60E	22S	3/2", Ct
N15W	58W	1/8",
N25E	27W	1",
N17W	12W	1/4", Ct
N46W	25W	1/2"
N-S	3W	1/4", Ct
E-W	20N	1/8", Ct
N54E	60SE	1/4", Ct
E-W	30N	1/4", Ct
N18E	82E	1/4", Ct
N39W	13SW	1/8"
N3E	60E	1/8", Ct
N42E	20SE	1/8", Ct
N42E	20SE	1/16",
N45E	23NW	1/2", Ct
N33W	45SW	1/8"
N40E	55NW	1/8", Ct
N45E	90	1/8", Ct
N18E	55W	1/8"
N55E	15NW	1/8"
N22E	56W	1/8", Ct
N25W	42W	1/8"
N77E	90	1/4", Ct
N48E	30NW	1/8"
N37E	65NW	1/8"
N82W	35S	1/8", Ct
N14E	15W	1/4", Ct

Figure C.2 Log of core Boring NCG 47.

PROJECT DUGOUT			
BORING NO.:	NCG 48		
LOCATION (NEVADA STATE COORDINATES):	N 853,170 E 594,057		
ANGLE OF BORING:	Vertical	TYPE OF BORING:	NX - Diamond
BEARING:		DRILLING AGENCY:	WES
EL TOP OF HOLE:	5387.12 ft MSL	DEPTH TO WATER TABLE:	Not encountered
TOTAL DEPTH:	120.0 ft	HOLE STARTED:	4 June 1965
TOTAL CORE RECOVERY:	95.1%	HOLE COMPLETED	8 June 1965

EL FT MSL	DEPTH FT	DESCRIPTION	CORE
5387.1	0	SILT; tan; with caliche and fragments of basalt	
5383.7		Top of Rock	50
	5	VESICULAR BASALT; dk gry; 20% dispersed ves, avg 1/8 in. long; subspherical down to 10 ft, flattened below 10 ft.	85
			89
			100
	10	No water returned below 7.3 ft	84
	15	Gradation to brn color at 15 ft	
5367.8		Gradational	96
	20	VESICULAR BASALT; brn; 25% flattened to subspherical ves; avg 1/4 in. long, dip 0 to 10 deg.	
	25		96
	30		
5354.5		VESICULAR BASALT AND DENSE BASALT; in alternating layers; ves range 5 to 25% by volume in ves layers decreasing generally downward.	
	35		91
	40	Fractures parallel flow layers	
		44 to 45.5 ft, numerous thin, discontinuous veinlets of calcite dipping 10 to 15 deg.	88
	45		71
5341.1		DENSE BASALT; gry; widely spaced thin layers of ves dipping 0 to 20 deg.	
	50		100
	55	DENSE BASALT; gry, massive	100
	60		100
	65		60
	70		97
		Anomalous magnetism observed at the depths: 42.8 to 45.1 ft; 49.4 to 52.4 ft; 57.4 to 58.1 ft	100
	75		100
	80		100
	85		
	90		100
	95		
	100		

BORE HOLE CAMERA JOINT DATA

STRIKE DEG	DIP DEG	WIDTH & FILLING
N55W	90	1/4", Ct
N65E	80S	>3/2", Ct
N5E	90	1/16", Ct
N-S	20W	1/2"
One joint, one fresh fracture		
N50E	90	1/4"
E-W	20N	4"
N20W	70W	3/8", Ct
	10W	1/4"
N60E	40N	1/8"
N40W	45SW	1/8", Ct
N80E	80N	1/8"
N75E	70S	1/8", Ct
N65W	75N	1/8", Ct
N35E	45W	1/8", Ct
N60W	65N	1/4"
	0	1/2"
N20W	30W	1/4", Ct
	10N	1/2"
	0	1/4"
N80W	60N	1/2", Ct
N50E	55NW	1/4", Ct
N85E	20S	1/2"
N20W	45W	1/4"
N25E	65E	1/8"
	10W	1/4"
N60E	90	1/4"
N65W	20N	1/2", Ct
N5E	30W	1/4"
	0	1/8"
	0	1/4"
N15E	90	1/8", Ct
	0	3/8"
	10S	1/8", Ct
N45E	80SE	1/8"
N75E	15N	1/4", Ct
	10W	1/4"
N-S	50E	1", Ct
N5W	75E	1/4", Ct
N75W	90	1/4", Ct
Two fresh fracture		
N10W	15W	1/16"
N-S	85E	1/32"
N45E	45SE	1/8"
N70W	80S	1/8", Ct
	10NW	1/16", Ct
	10N	1/8", Ct
	10N	1/8"
	10NW	1/8"
	0	1/8"
N70W	75N	1/8", Ct
N55W	90	3/8", Ct
One fresh fracture		
	5E	1/4"
E-W	80S	1/8", Ct
N25W	30E	1/8"
N85W	90	3/8", Ct
N25W	50E	1/4"
N65W	55NE	1/4"
N35W	35NE	1/4", Ct
N85W	45N	1/4", Ct
E-W	50S	1/4"
N45W	35NE	1/8", Ct
N55W	40NE	1/8"
N85W	90	1/4"
N20W	85N	1/4", Ct
N85E	90	1/4", Ct
	10S	1/8"
N35W	50N	1/8", Ct
N20W	75NE	1/8", Ct
N50E	40SE	1/8", Ct
N45E	40SE	1/16"
Three fresh fractures		
	0	1/16", Ct
N65W	30S	1/32", Ct
	5E	1/16", Ct
N55W	85SW	1/4", Ct
	20SW	1/16
	30NW	1/4"
N-S	50E	1/8"
N30W	90	1/8", Ct
N10W	80SW	1/4", Ct
	0	1/4"
N30W	50NE	1/8", Ct
N35E	60E	1/8"
N5E	45W	1/8"
N85W	90	1/4", Ct
N65E	45SE	1/8", Ct
N50W	80SW	1/4", Ct
	0	1/8"
N25W	30NW	1/8", Ct
	5SW	1/4"
N20W	25NE	1/16", Ct
N50W	35NE	1/4"
	0	1/4"
N85E	75S	1/8", Ct
N60E	55SE	1/8", Ct
E-W	20S	1/8"
N45W	30SW	1/32", Ct
N75W	25S	1/32", Ct
N40W	30NE	1/16", Ct
N70E	35SE	1/16", Ct
E-W	15S	1/16"
N55E	20SE	1/16", Ct
N5W	20W	1/4", Ct
E-W	15S	1/4", Ct

(Continued)

PROJECT DUGOUT			
BORING NO.:	NCG 48 (Continued)		
LOCATION (NEVADA STATE COORDINATES):			
ANGLE OF BORING:		TYPE OF BORING:	
BEARING:		DRILLING AGENCY:	
EL TOP OF HOLE:		DEPTH TO WATER TABLE:	
TOTAL DEPTH:		HOLE STARTED:	
TOTAL CORE RECOVERY:		HOLE COMPLETED	

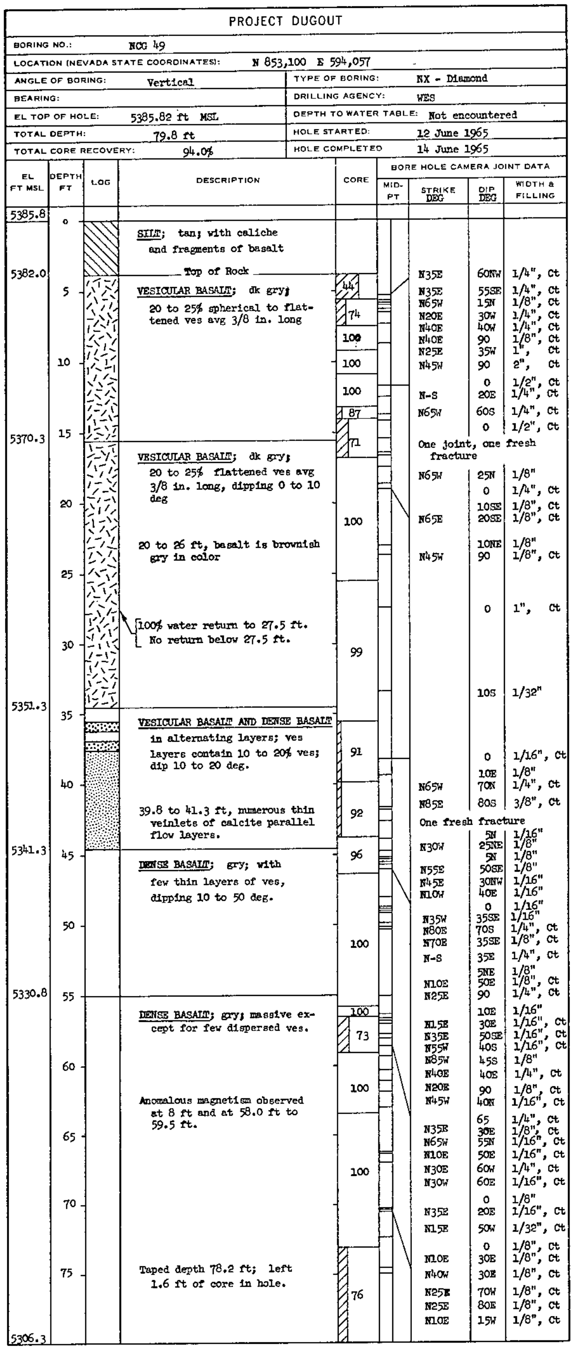
EL FT MSL	DEPTH FT	DESCRIPTION	CORE
5287.1	100	DENSE BASALT, as above	100
	105		
	110	107 to 120 ft, numerous discontinuous thin white layers, dipping 30 deg; probably healed flow layers.	100
	115		92
5267.1	120		

BORE HOLE CAMERA JOINT DATA

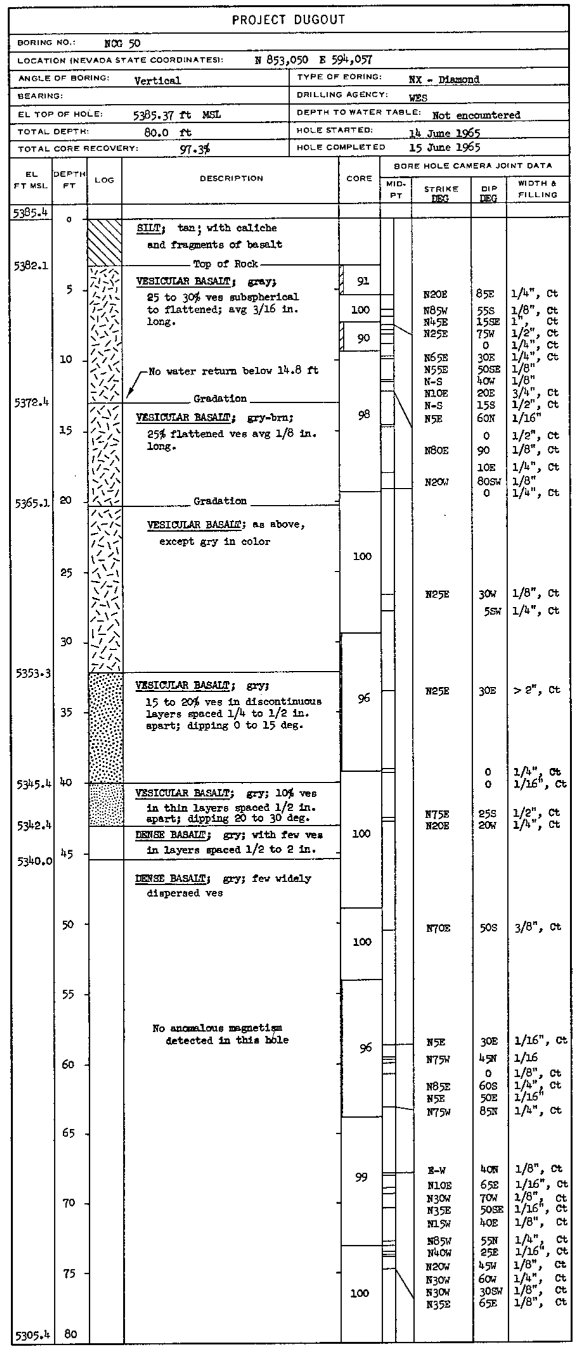
STRIKE DEG	DIP DEG	WIDTH & FILLING
N45E	50SE	1/16", Ct
N20W	90	1/8", Ct
N65E	20SE	1/8", Ct
N-S	15W	1/8", Ct
N15E	10E	1/8", Ct
N55E	35SE	1/4", Ct
N35E	75E	1/8", Ct
N50W	15NE	1/8", Ct
N45W	15NE	1/8", Ct
N35E	75SW	1/8", Ct
N10E	55E	1/4", Ct
N25E	30E	1/8", Ct
N75E	30N	1/8", Ct
	0	1/8", Ct
Bottom of photographs 116 ft		

Bottom Depth: 120.0 ft
Bottom Elevation: 5267.1 ft

Figure C.3 Log of core Boring NCG 48.



Bottom depth: 79.2 ft
Bottom elevation: 5306.3 ft



Bottom Depth: 80.0 ft
Bottom Elevation: 5305.4 ft

Figure C.4 Logs of core Borings NCG 49 and NCG 50.

APPENDIX D

RESULTS OF POSTSHOT VIBRATORY AND SEISMIC INVESTIGATIONS

This appendix is an abstract of Reference 21, which summarizes vibratory and seismic investigations conducted by the Soils Dynamics Branch, WES, during the month of December 1965. The investigation was conducted for the purpose of evaluating the dynamic in situ testing techniques and associated equipment as a means for determining boundaries of subsurface fracture zones in the immediate vicinity of craters produced by explosions. Results bearing on the site conditions are emphasized in this appendix.

D.1 SEISMIC INVESTIGATION

Refraction seismic tests were conducted at the southern edge of the crater to determine the velocities of compression waves traveling through the subsurface materials. A total of eight seismic traverses were run along four lines by detonating a charge at each end of the line for a forward and reverse traverse to provide more detailed coverage.

The data obtained from these tests were somewhat erratic, and analysis was consequently inconclusive. The erratic data are attributed to the discontinuous nature of the undisturbed subsurface materials. There was no indication of any definite fracture zones, because, as was subsequently determined, geophone spacing and traverse orientation did not provide sufficiently detailed coverage in the area of interest.

The seismic (compression) wave velocities varied from 2,100 to 8,500 fps. The depths of velocity changes were computed by conventional refraction seismology techniques, but they are somewhat inconsistent. However, taking the seismic traverses collectively, the velocities apparently can be grouped into four categories which seem to characterize the primary geologic divisions known to exist in this area. A meaningful correlation between the velocities and geologic divisions established by borings can be made in a few cases, as follows:

Geologic Unit	Depth from Surface	Velocity Range
	feet	ft/sec
Soil overburden	0-8	2,100-3,500
Vesicular basalt 20% vesicles	8-35	5,000
Vesicular basalt 10% vesicles	35-42	6,500-7,000
Dense basalt	42+	8,000-8,500

D.2 VIBRATORY INVESTIGATION

Vibration tests were conducted to determine the length of shear waves generated by a vibrator operated at controlled frequencies. From this information, shear wave velocities were computed. The traverses extended east and west from the south trench at distances of 200 and 310 feet from the south edge of the apparent crater. Other traverses were oriented in the north-south

direction along the trench perpendicular to the south edge of the crater. The original concept was to start the test program as near to the crater as possible and to run parallel traverses at increasing distances while noting changes in shear wave velocity (if any) as the limit of blast-induced fractures was passed. A total of nine vibration traverses were run in the vicinity of the crater.

Analysis of the vibration traverses relative to wavelength, velocity, and depth showed that the east-west traverses exhibited similar results. The velocities were found to be constant at each frequency for the entire extent of the traverse. The traverse eastward from the trench 200 feet south of the lip showed velocity trends which could be directly correlated to known geologic horizons (Figure D.1). The traverse was typical of all traverses. A geologic profile constructed from boring information in the immediate area substantiates the velocity correlations. It will be noted that the major break in velocities occurs at a depth of about 42 feet, which is the approximate contact between the vesicular and the dense basalt.

It was noted that unusual, seemingly inconsistent changes were occurring in measured distances between vibrator half-wavelengths along traverses perpendicularly approaching the crater. When these changes were noted, careful attention was given to every wavelength measurement in 1-foot increments. Plots of number of waves versus

distance readily showed the changes in wavelength as distance from the vibratory source increased. Figure D.2 shows a typical plot of the data obtained along one traverse (V-8). Table D.1 gives the computed values of depth of wave penetration and wave velocity for indicated distances from the vibration at each frequency and wavelength for all three north-south traverses.

These data were used to construct the cross section of subsurface conditions (Figure D.3). The solid contours were determined from actual shear wave velocity data. The dashed contours represent the presumed preshot velocity conditions in areas that appear to have been most significantly disturbed by the detonation. The extent of major subsurface disturbance resulting from the shot is thought, on the basis of this investigation, to be generally defined by the intersection of the solid and dashed contour lines. This area appears to be the departure from the norm, which was the prime basis for a detailed analysis of the data in this area to determine the limit of major disturbances. The boundary was constructed by connecting the points where the first abrupt velocity increase occurred for each frequency (considering all traverses perpendicular to crater) when proceeding away from the crater.

After postshot geological data had been analyzed and an outer limit of blast fracturing approximated, the vibratory data were reexamined to try to identify this subtle boundary. A velocity

increase, which was also frequency-dependent, was tentatively identified at an average distance of approximately 220 feet from ground zero. Considering only the data below a depth of 20 feet, a line was constructed to show the limit of this second velocity increase. This boundary was interpreted as the possible limit of minor disturbance resulting from the detonation. One unexplained point of interest in Figure D.3 is the high-velocity zone which occurs at a depth of about 65 to 75 feet and extends over most of the traverse length. This is represented by the hatched area in the figure. This 6,000-ft/sec zone within the 2,000+ contoured area could possibly be caused by a layer of very dense basalt or an interface existing between the basalt and other materials such as revealed in some boring logs.

TABLE D.1 SHEAR WAVE VELOCITY DETERMINATIONS, NORTH-SOUTH TRAVERSES

Traverse	Frequency	Wavelength	Distance from Vibrator	Depth of Penetration	Velocity
	cps	feet	feet	feet	ft/sec
V-2	100	6	0-12+	3	600
	75	12	0-25+	6	900
	50	25	0-40+	12.5	1,250
	40	42	0-65+	21	1,680
	35	50	0-80+	25	1,750
	20	104	0-160+	52	2,080
	16	140	0-145+	70	2,240
	13	156	0-155+	78	2,030
	12	183	0-185+	91.5	2,200
	11	206	0-210+	103	2,270
V-8	50	8	0-14	4	400
		20	14-40	10	1,000
		32	44+	16	1,600
	45	11	0-15	5.5	500
		27	15-65	13.5	1,200
		34	65+	17	1,530
	40	12	0-14	6	480
		39	14-115	19.5	1,550
		50	115+	25	2,000
	35	112	0-12	6	420
		47	12-115	23.5	1,650
		63	115+	31.5	2,200
	30	28	0-18	14	840
		55	18-100	27.5	1,650
		80	100+	40	2,400
	28	35	0-22	17.5	980
		66	22-100	33	1,850
		100	100	50	2,800
	25	92	50	46	2,300
		60	50-75	30	1,500
		92	75+	46	2,300
	20	128	0-85	64	2,560
		75	85-155	37.5	1,500
		100	155	50	2,000
	10	170	0-170	85	1,700
	9	240	0-240	120	2,160
V-9	56	10	0-20	5	560
		44	20-76	22	2,460
		4	76-84	2	220
		25	84-164	12.5	1,400
		17	164-235	8.5	950
		12	2,354	6	670
	46	30	0-18	15	1,380
		144	18-183	72	6,620
		40	183-232	20	1,840
		19	232+	9.5	870
	40	43	0-62	21.5	1,720
		131	62-240	65.5	5,250
		20	240+	10	800
	35	65	0-70	32.5	2,280
		150	70-145	75	5,250
		44	145-255	22	1,540
		24	255+	12	840
	30	69	0-150	34.5	2,080
		92	150-230	46	2,760
		30	230+	15	900
	25	98	0-290+	49	2,450
	20	127	0-295+	63.5	2,540
	15	164	0-290+	82	2,460
	10	244	290+	122	2,440

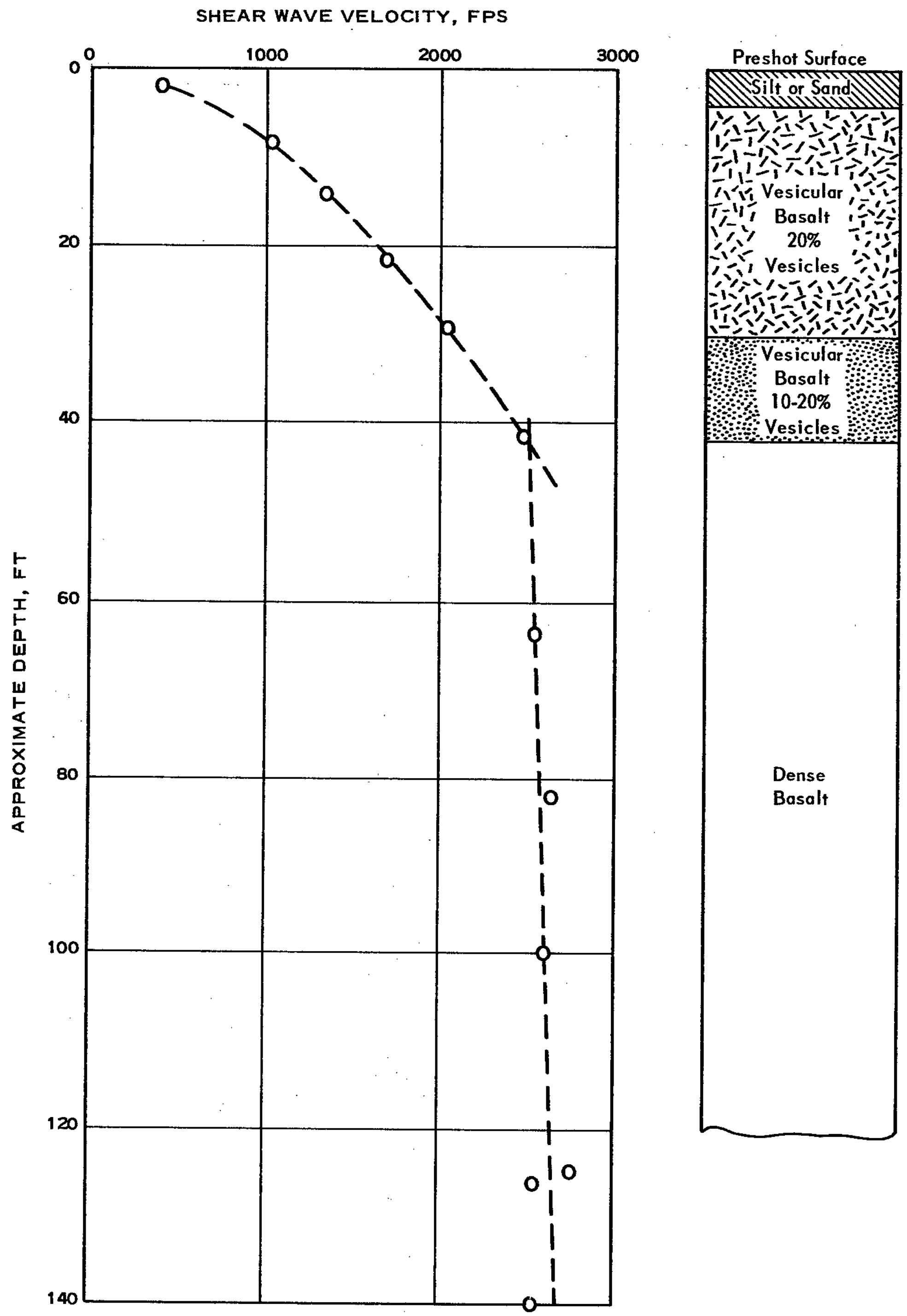


Figure D.1 Shear wave velocity versus depth with subsurface profile along eastward traverse from south trench at distance of 200 feet from crater lip.

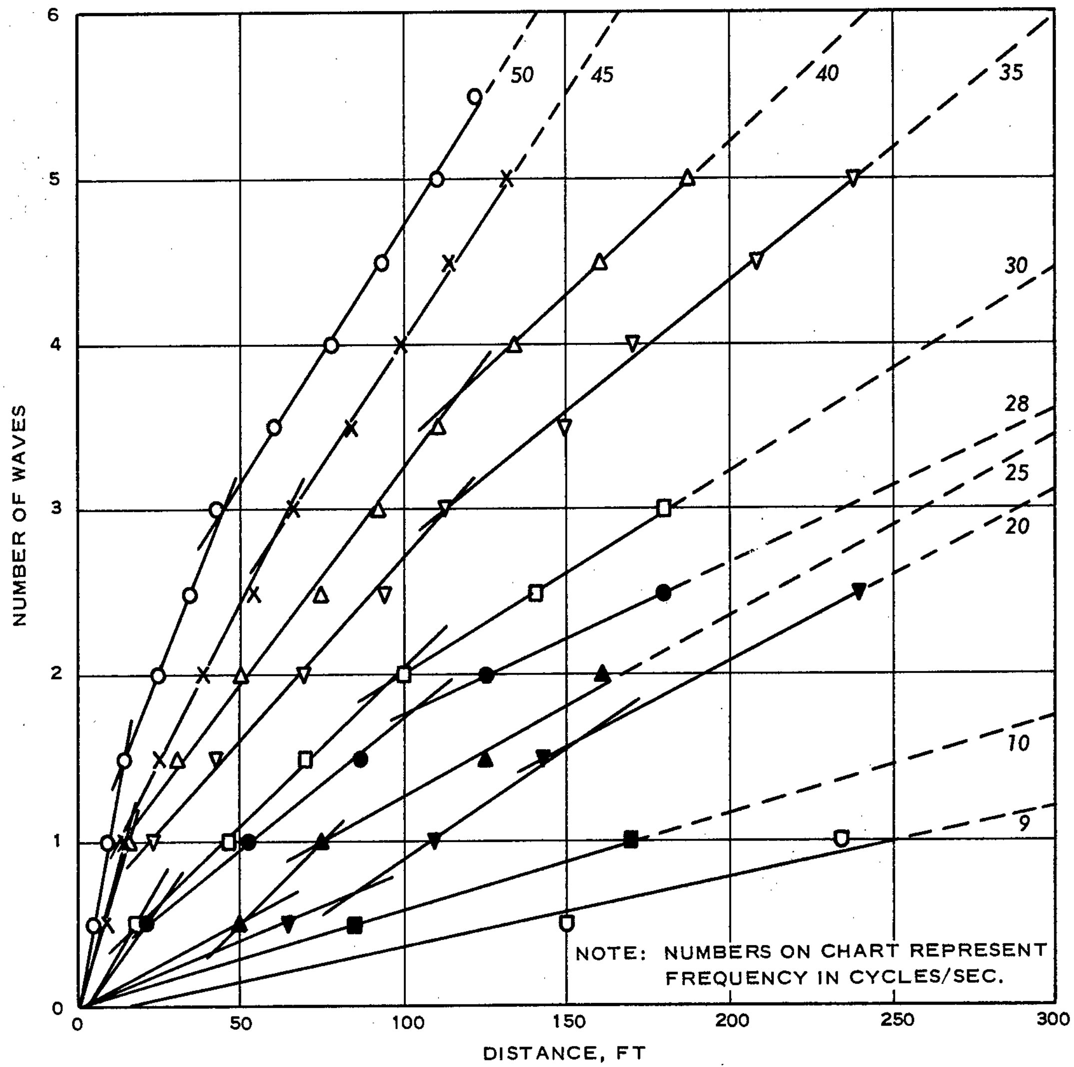


Figure D.2 Number of shear waves versus distance, traverse V-8.

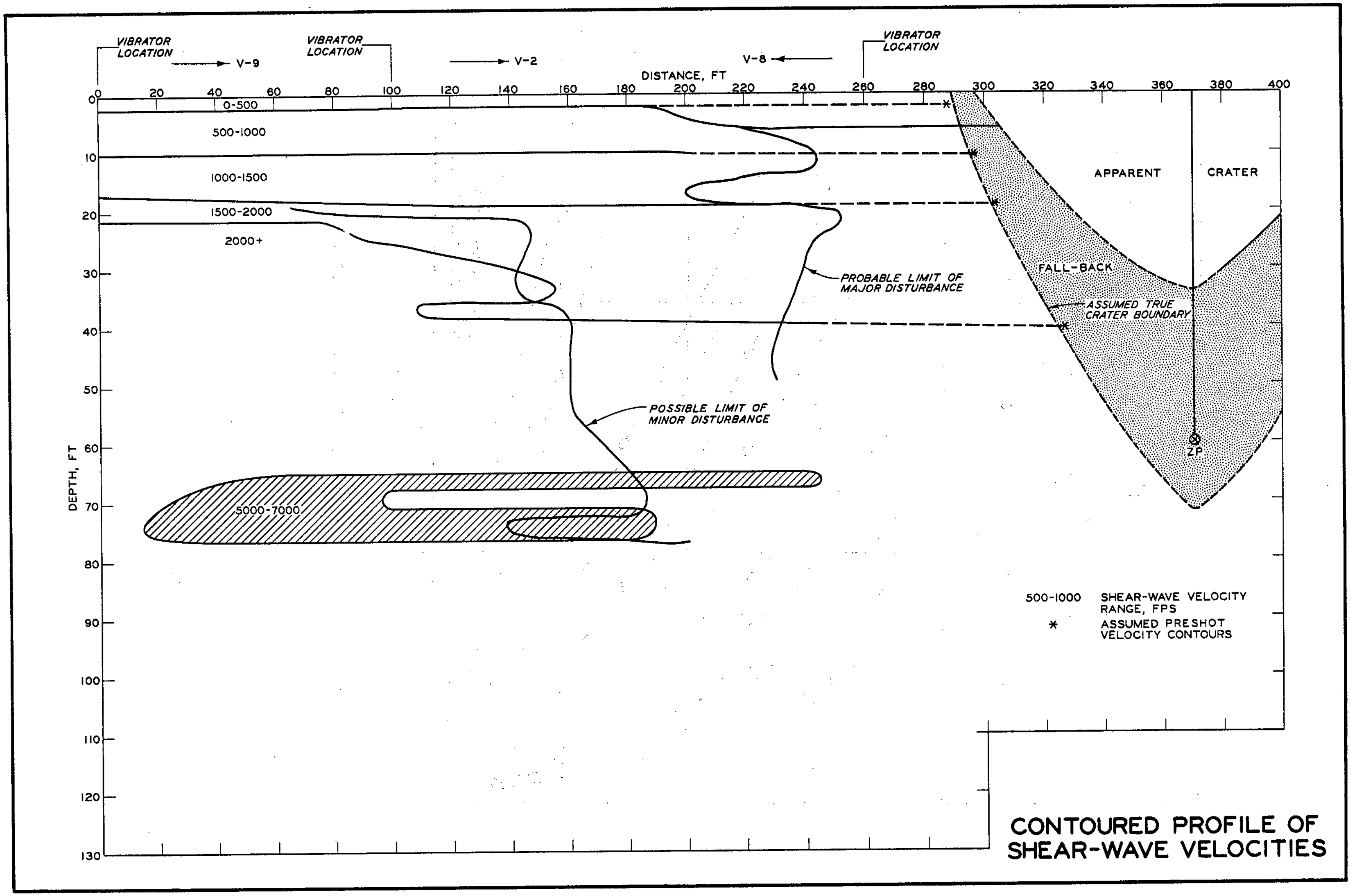


Figure D.3 Shear wave velocity profile.

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